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MARCH—APRIL 1949

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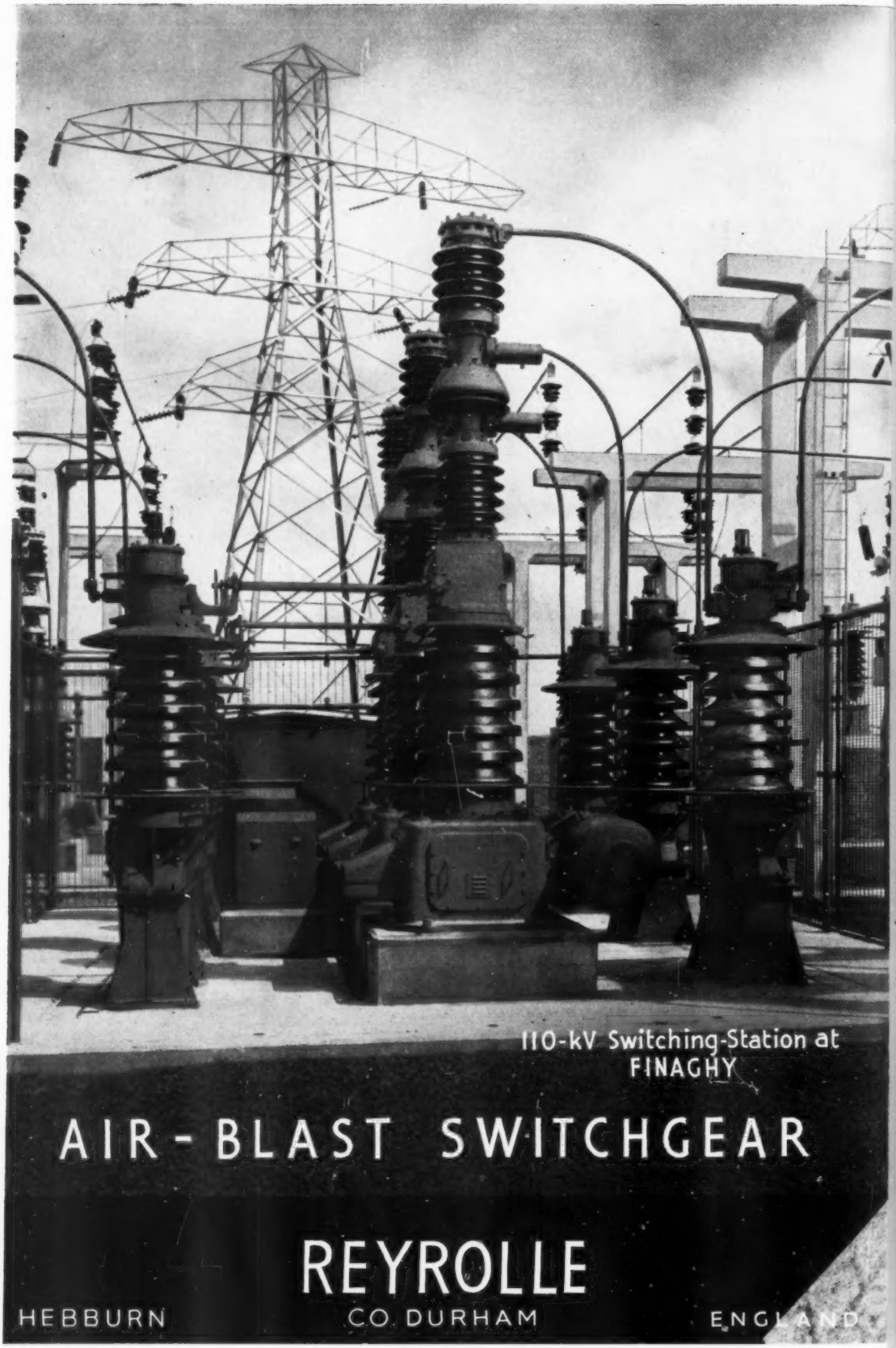
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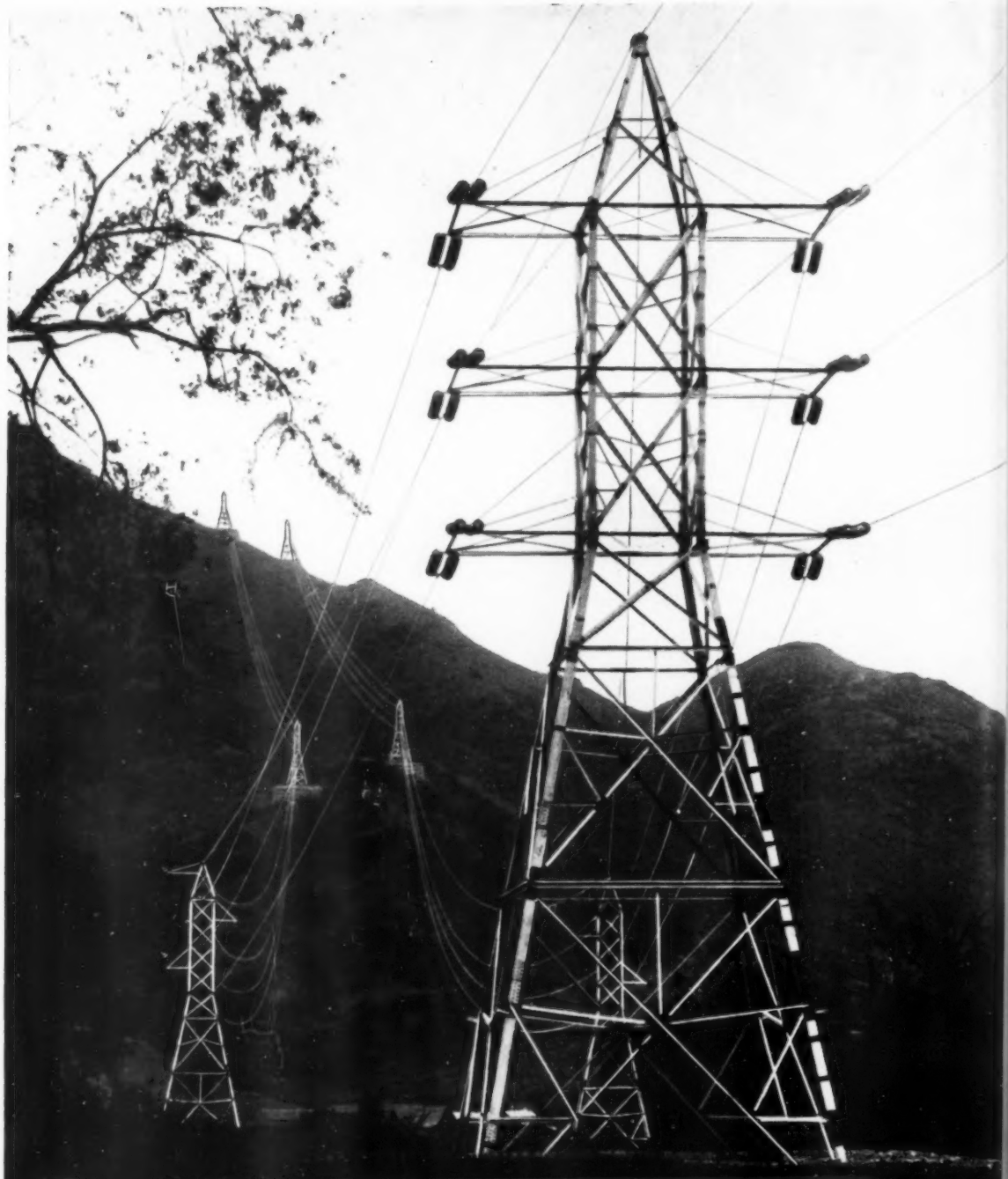
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# WATER POWER

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# The Nile and Egypt

THE recent announcement in Parliament that the Governments of Great Britain and Egypt had reached agreement on some of the knotty problems affecting the exploitation of the Nile waters has removed the chief political obstacle to a praiseworthy scheme of industrial development. To produce the most beneficial results however it will be necessary to carry out engineering works on the main Nile in the Sudan, on the Blue Nile in Ethiopia, and on the White Nile in Uganda and the British Government "looked forward to the participation in this great undertaking of the Ethiopian Government and also of the Belgian Government, whose approval has still to be sought." The exact manner in which these Governments would share in the major scheme remains to be established; but with their co-operation in the full development of the greatest natural power potential in Africa the advantages accruing to all parties concerned would be enormous.

The complete proposal requires the damming of the White and Blue Niles where they flow out of Lake Tana (owned by Ethiopia), Lake Victoria in Uganda, and Lake Albert in the Congo (owned by Belgium); the cutting of a canal to by-pass the swamps in the Southern Sudan, and building more reservoirs on the main Nile similar to that at Assuan which was described in the previous issue of *WATER POWER*.

On another page a description is given of the Owen Falls project, based on a Colonial Office report prepared by two British firms of consulting engineers, Sir Alexander Gibb & Partners and Messrs. Kennedy & Donkin. By building a dam near Jinja, in Uganda, with an associated hydro-electric works which would ultimately house at least eight Kaplan turbines coupled to alternators of 15,000 kW each, Lake Victoria would assume responsibility for the adequate storage of water for the future needs of Egypt and the Sudan.

Only by controlling the Nile headwaters can Egypt, who would be the principal beneficiary from these complicated schemes, be assured of a useful water supply during the low years; and this is of vital importance to the country if her population continues to grow at its present rate. Increased irrigation would greatly benefit the Sudan, and the infested swamps of the Sudd region might eventually be eliminated. The establishment of a hydro-electric power station at Owen Falls will offer an unrivalled opportunity for raising the standard of living by attracting new industries to Uganda and by making available a supply of electricity for domestic use at a price the population can afford to pay.

Large reserves of rock phosphates are known to exist in Uganda and other territories surrounding Lake Victoria, and we learn that the experience of the Tennessee Valley Authority — that admirable example of co-operative effort—will be applied to the exploitation of the mineral deposits, which will be turned into valuable fertilizer when large quantities of electricity become available in those distant places. A moderate degree of industrialization would also come to Ethiopia with the use of hydro-electric power.

An even broader economic picture emerging from great projects of this character has been hinted at by the British Minister of State, Mr. Hector McNeil. He has placed on record his firmly held conviction, to which we readily subscribe, that only by investment in such areas as Africa and South-East Asia can Europe, and particularly Great Britain, find a reasonable chance of economic recovery. His further remark that during the next few years the demand for capital for development purposes would far exceed the supply was yet another indication of the supreme importance of great projects to the new world economy that was now gradually arising out of the war's chaos.

"Investor and borrower alike (he said) will see in Africa and South-East Asia the most attractive sources . . . Only by investment in those areas can the terms of trade, which have been running against us for some time, be redressed to afford us a reasonable opportunity of recovery." That, indeed, is a main reason for the great schemes of development the British Government is to-day contemplating, and furthering, in many parts of the African Continent, and in which water power is without question destined to play a major rôle.

Particularly in Europe, where the thirst for electricity is insatiable, other sources of water power are being sought and it is of more than academic interest that some further attention has been given lately to the possibility of harnessing the immeasurable energy in the tides. Man has ever felt the urge to use the ocean's restless movement, and to subdue the ebb and flow of the those imponderable masses of water; but only comparatively recently has the means been given to him whereby, in certain circumstances, the latent power could be extracted efficiently if not with attractive profit. The increasing cost of solid fuels used in power generation has given impetus to hydro-electric generation; and some justification for the further examination of tidal power projects.

Consideration is being given to schemes in those parts of the world where there is a combination of industrial load for the developed energy within reasonable distance, and an estuary where the ebb and flow of the tide is concentrated within relatively convenient bounds. But no tidal scheme has yet been put into practical operation. Whenever the matter is brought

up for discussion, the preponderant note among those best qualified to judge is that while technically the schemes are sound, economically they are doubtful.

In Great Britain successive Commissions of Inquiry have postulated, for instance, that the Severn Barrage would not be practicable at the time the Commission made its report, though it might be that in a few years' time, with the rise of coal costs, it could compete successfully with thermal stations on the grounds of saving fuel alone. When a later examination was made, the costs of the vast civil engineering structures required had again risen steeply; then the new Committee of Inquiry found that the coal cost would have to rise still further before the economic equation would be balanced. That this has happened yet again was shown when a recent paper was given at the Institution of Electrical Engineers by Mr. H. Headland. The discussion indicated that the British Electricity Authority once more expressed the view that the civil costs would be too great in proportion to the present price of coal.

Yet another aspect, which causes economists to hold back from plunging into a positive decision in cases where tidal schemes rest on a fine point of economic balance, is the great length of time such vast civil engineering constructions are likely to take. As much as twelve and fifteen year periods have been given by authorities who have closely investigated tidal power plans. It is realized that firm estimates, in relation to rapidly changing labour rates and costs generally, including rates of interest, are almost impossible; this militates against proper long-term financial planning and delays the advent of tidal power.

## Developing Rhodesia: Report in Preparation

DEVELOPMENT of nearly a third of the entire area of Southern Rhodesia is the subject of a final report now in preparation for the Government of that country by a leading firm of civil engineers and public works contractors in London, Sir Alexander Gibb & Partners. These areas include the Lundi and Sabi valleys, which in turn must have a profound bearing on the economic future of the country itself. While the report is not yet available it is understood that there will be recommendations to the effect that the schemes envisaged should come under the direction of a single central authority, similar in its broad aspects to the Tennessee Valley Authority. Irrigation on a large scale will be needed, and dam sites have already been established. These and other plans for conserving water resources are estimated to involve an expenditure of approximately £10 million in the next fifteen years or so.

## International Bank Loan for Brazil

BRAZIL is giving an important place in its development plans to hydro-electric power, the significance of which has received international support. The International Bank for Reconstruction and Development announces that it has decided to grant a 75 million dollar loan to the Brazilian Traction, Light and Power Company, and one of the main purposes is "to assist in financing the expansion of hydro-electric power facilities" in Brazil. The intention of the company itself is to spend a considerable proportion of the proceeds of the loan in the purchase of equipment, and for this purpose suppliers are being sought in the United Kingdom, United States, Canada and in continental Europe. On the financial side the Canadian Government has signified its approval to the use by the Bank in its loan operations of up to 8 million Canadian dollars out of the Government's subscription to the capital of the bank, and the British Government similarly has agreed to the use by the Bank of an amount up to £500,000 of the United Kingdom's subscription to the Bank's capital. The Bank will disburse these amounts in connexion with purchases eligible under the loan agreement to be made by the company and the United Kingdom respectively.

## Kariba Gorge Project on the Zambesi

SIR WILLIAM HALCROW, chairman of the panel of consulting engineers who are to advise the government of Southern Rhodesia on the Kariba Gorge hydro-electric power project on the Zambesi River, has conducted preliminary discussions with members of the Inter-Territorial Hydro-Electric Power Commission. Three other engineers will be joining him early in July, and it is expected that their joint report on the scheme will be completed towards the end of the year. Other members of the panel now engaged on work connected with the Kariba Gorge scheme are two electrical engineers, Mr. C. H. Pickworth and Mr. G. Kennedy, and a civil engineer, Mr. H. J. F. Gourlay. Sir William Halcrow has put the case for hydro-electric schemes as against coal fired plant quite simply. One of its main advantages, he urges, is that "when you have spent your money, annual costs consist only of interest on capital and amortisation fund. Cost of energy therefore is at its highest in the first year of running. With the operation of the amortisation fund, writing off so much each year, interest charges come down, and therefore the cost of power also."

## Experiments with Wind Power

MR. TOM JOHNSTON, chairman of the Scottish Tourist Board, at a recent Press conference in London, said that about 102 schemes for harnessing water power were already planned for the North of Scotland; when these were in operation the electricity produced would equal about a seventh of the present electricity resources of Great Britain.

Hitherto, he said, water power in Scotland had run waste to the sea and there had been vast soil erosion. This was to be stopped. Hydro-electric plants at Morar and Lochalsh were now running and it was expected that by this winter two other schemes would be in operation near Loch Sloy and Loch Clunie. The profits earned by these stations through supplying electricity to the national grid would help to provide transmission lines to rural and isolated areas. Large distribution schemes were in hand and more were progressing and when completed would provide over now in hand and when completed would provide over 40 per cent. of the present total electricity used in Scotland.

Mr. Johnston said that the Scottish Electricity Board, in conjunction with the Electricity Development Association, was experimenting with wind power. There had been one such experiment in the Orkney islands and another would be tried in the island of Lewis. If the experiments succeeded, wind power would be used to augment water power in the generation of electricity.

## Six Nozzled Impulse Turbine

MR. V. L. BATAILLARD, of Merz & McLellan, writes:—"The claim is made in the first number of *WATER POWER* that a set to be installed at the Bridge River plant, British Columbia, will be the first in the world to utilize six nozzles on an impulse turbine. This claim is more than 40 years late, as the British Aluminium Company Limited were operating in 1908 a horizontal shaft Pelton wheel with six nozzles on the same runner driving an alternator, ensuring power supply during the construction of the Kinlochleven Scheme. This Pelton wheel was built by Th. Bell and Company, Kriens, Switzerland."

## Unrecorded Hydro-Electric Installations

ALTHOUGH there is a considerable amount of technical and other information about the developments, in the hydro-electric field, in the major countries of the world where hydro-electric energy forms a great—and increasing—proportion of the national supply of the power consumed, there are large numbers of lesser-known hydro-electric installations whose existence do not appear to be recorded in the standard statistical surveys. Among them is Afghanistan, a largely undeveloped country in the industrial sense, where not less than twelve water turbines are installed. They exist at Jabal-us-Siraj (4), and Wardak (3); these two stations supplying the capital, Kabul. Other installations are at Kandahar (1); Herat (1), and Pul-i-Khumri (3). The combined capacity of the Kabul stations is 5,700 kW, while that at Kandahar has a 300 kW set, the remaining installations being of similar size.

## Four-year plan for Algeria

IN the last eighty years the population of Algeria has trebled itself. Some sixty million acres of the country are potentially productive and it has accordingly been decided to develop some of the available water power on the basis of a four year plan. The natural mountain lakes which can supply water for irrigation and power lie some hundred miles to the south of the Mediterranean shore. Generation of power will be relatively cheap since a large part of the civil engineering works costs will be debitable to the irrigation plans.

The target for the moment is 700 m kWh which will be made up in more or less equal parts by thermal and hydro-electric power—at the present time water power provides only a quarter of the total. The annual increase in electricity consumption is such that it doubles itself in ten years, and it is expected that this will absorb all the power to be made available while allowing the 30-year-old Port of Algiers thermal station to be shut down.

The project is based mainly on utilising the water of the Chott Ech Chergui, a natural lake to the south-west of Oran. From this lake the power available will be 150 MW which will be transmitted to the area of load by two 150 kV lines. The annual availability of water from this source is expected to be of the order of 500 million cubic metres. The whole project is expected to cost about eighty thousand million francs.

## Siam looks to the Future

AN agreement has been reached between the Siamese Government and the International General Electric Company of America, whereby the company will investigate the possibilities of developing Siam's hydro-electric resources. A survey was undertaken before the war, but as yet no hydro-electric plants have been constructed.

It is generally assumed that the first power station will be built at Kanburi, about one hundred miles north-west of the capital, Bangkok. Such a station could possibly supply the whole of the central plain area and the capital itself. When the new survey has been completed, it is thought that a loan will be sought from the International Bank, in order to finance such schemes as the report indicates are likely to be of commercial value.

## Tidal Power and the Severn Barrage

THERE was a large attendance at the joint meeting of the Institutions of Civil and Electrical Engineers held in the I.E.E. building on February 5 when Mr. H. Headland (Messrs. Kennedy and Donkin) presented his paper on "Tidal Power and the Severn Barrage."

The paper, which is summarized in this issue, was well received and several eminent engineers made contributions to a lively and interesting discussion. Sir John Hacking (B.E.A.) summed up the position succinctly by saying that tidal power always seemed uneconomic at the time, though it was expected to be economic in the near future, usually on the assumption that coal prices would rise. This seemed to us to be a kindly way of relating it to the well known arrangement of "Jam yesterday—Jam to-morrow—but no Jam to-day." He said the Severn Scheme would not save a single kW of generating plant elsewhere, but it would be of great value as a potential coal saver. It was a scheme which should be reserved for a time of trade depression.

Sir John Kennedy (Uganda Electricity Board) suggested that the use of geared alternators might be considered as a means of reducing the cost of foundation works and stated that the inclusion of the road and rail bridge mentioned in the 1937 Report might be reconsidered.

Other speakers emphasized the many engineering, economic and even prestige aspects of the project. The author briefly replied.

We came away after a pleasant and instructive evening feeling that the Severn Barrage Scheme, which had received another airing, had been "damned by faint praise."

*The falls at Harspränget*

# Swedish Hydro-Electric Resources

By Fil. Lic. Viking Källström, of the Swedish Board of Trade. Only a little more than one third of the economically available resources are harnessed; consumption is analyzed.

*L'auteur montre qu'à peine un peu plus du tiers des ressources économiquement exploitables est mis en valeur en Suède, ou cependant la consommation d'électricité par habitant dépasse celle des Etats-Unis. De nouvelles installations hydro-électriques sont en construction ou projetées, qui augmenteront d'environ 40%, la capacité de production de houille blanche en 1953. L'article analyse et explique la consommation d'énergie électrique en Suède.*

*Se dispone de manifiesto que solamente algo más de una tercera parte de los recursos económicos disponibles están siendo aprovechados; pero el consumo de energía eléctrica por cabeza de la población sueca excede la de los Estados Unidos de Norte América. Se llevan proyectadas o están en curso de construcción nuevas instalaciones hidroeléctricas que proporcionarán un aumento del 40 por ciento en la capacidad de las instalaciones de fuerza hidráulica del país en el año 1953. Se explica el consumo de energía eléctrica en Suecia.*

THE coal resources of Great Britain have provided the basis for industrial development; but such resources are on the whole lacking in Sweden. The country has, however, comparatively large resources of wood, and of peat. The forests were severely used during the war, and in any case wood can find so many other uses as an industrial raw material that it is normally much too expensive to burn as fuel. The problem of using peat economically, on a large scale, remains unsolved. In these circumstances the very important water power resources of Sweden are of special value.

For centuries the power of the waterfalls has been harnessed industrially for iron works, mines, and mills associated with the processing of paper, flour and timber. The expansion of the Swedish saw mill industry was due principally to the steam engine; but towards the end of the century the gradual evolution of high tension electrical techniques enabled the modern hydro-electric epoch in Sweden's industrial history to begin.

**Total Water Power Resources**

The total water power resources of Sweden are estimated at 150,000 million kWh. This figure may not appear very impressive when compared with the corresponding total for the United States and Canada; but it still implies that Sweden, from this point of view, stands high among the European countries, the U.S.S.R. of course being excluded. The Swedish waterfalls are largely centred remotely in Northern Sweden, where there are few amenities to support any population; thus the water power cannot be utilised at its source. In fact the water power resources which are economically available amount to only 40,000 million kWh a year, which is slightly over one quarter of the total. The sketch map (Figure 1) indicates the disposition of the waterfalls, and it will be seen that the two most northern regions together approximately correspond to "Norrland."

At present a little more than one-third of the economically available water power resources are harnessed. The installed capacity (1947) amounted to about 2.7 million (turbine) kW. In certain industrial regions water turbines for direct driving of machinery still remain; but these prime movers represent a capacity equivalent only to about 80,000 kW, and further development is tending towards electrification. The total capacity of generators driven by hydraulic turbines is about 3 million kVA.

To indicate the comparison between water power and thermal power in Sweden, it should be mentioned that steam power generation mainly has the character of auxiliary plant in relation to the water power stations. In 1947 steam driven generators, having a total capacity of about 950,000 kVA, were in service.

According to a recent report, the total capacity of the water power plants in Sweden existing at the beginning of 1930 was 1.2 million kW. In the years just before the last war an average of 100,000 kW of water power machinery was put into commission each year, and during the war this figure rose to about 150,000 kW. After a considerable decline in the rate of installation of new plant towards the end of the war—a decline which was considered justified *inter alia* by an expected depression—the figure rose in 1945-47 to about 450,000 kW in each year. Table I shows the size of the new hydro-electric installations

TABLE I

| Year | Total kW | Yearly average kW |
|---|---|---|
| 1945-46 | 70,000 | 35,000 |
| 1947-48 | 260,000 | 130,000 |
| 1949-50 | 410,000 | 205,000 |
| 1951-52 | 610,000 | 305,000 |

in the course of construction or projected during the years 1945-1952.

The figures given in this table show that the constructional progress has been accelerated during the last few years, and the completion of the plants now under construction imply an increase of about 40% in the capacity of the country's water power plants. The calculated output in 1953 is approximately 20—21 milliards kWh, as compared with scarcely 14 milliards kWh in 1948. There are, however, certain risks that the construction programme may be delayed by equipment delivery difficulties, and the shortage of labour.

Most of the Swedish rivers that are considered important for power supply are characterised by their extremely wide variations in flow between one season and another; particularly those in Northern Sweden, where a great deal of the precipitation is stored as snow in the long cold season. This condition being unfavourable from the power supply point of view is, to a large extent, neutralised by regulation of the available water. There are schemes for regulation of the daily flow, the weekly flow, and the yearly flow, while in some cases large reservoirs have been constructed where water can be stored from one year to another. The largest lake in Sweden, the Vänern, having an area of 5,550 sq. km., with a reservoir capacity corresponding to 860 million kWh is a case in point. In 1938 the total capacity of developed reservoirs for this purpose, at 100% efficiency, was 2,028 million kWh, and in 1946 it had risen to 3,759 million kWh. With the additional capacity of temporary reservoirs representing 1,196 million kWh, the total volume of stored water in 1946 was 24,000 million cubic metres.

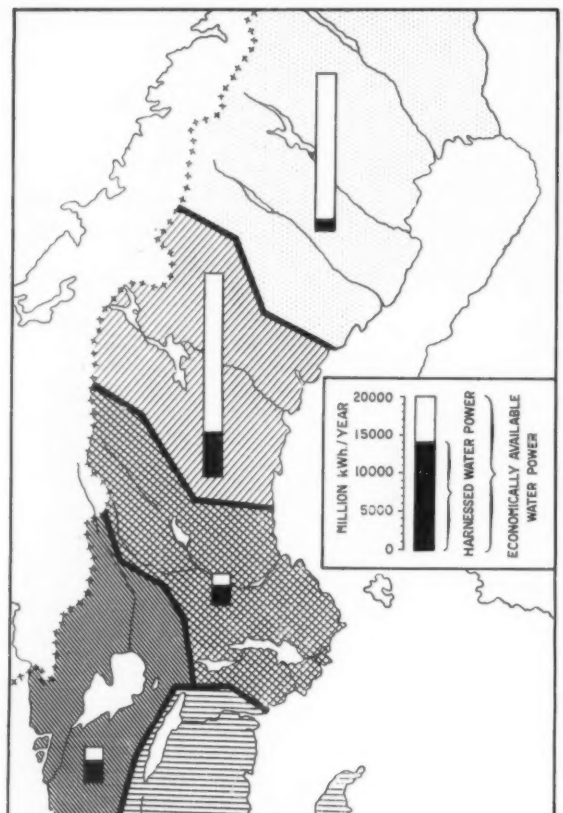


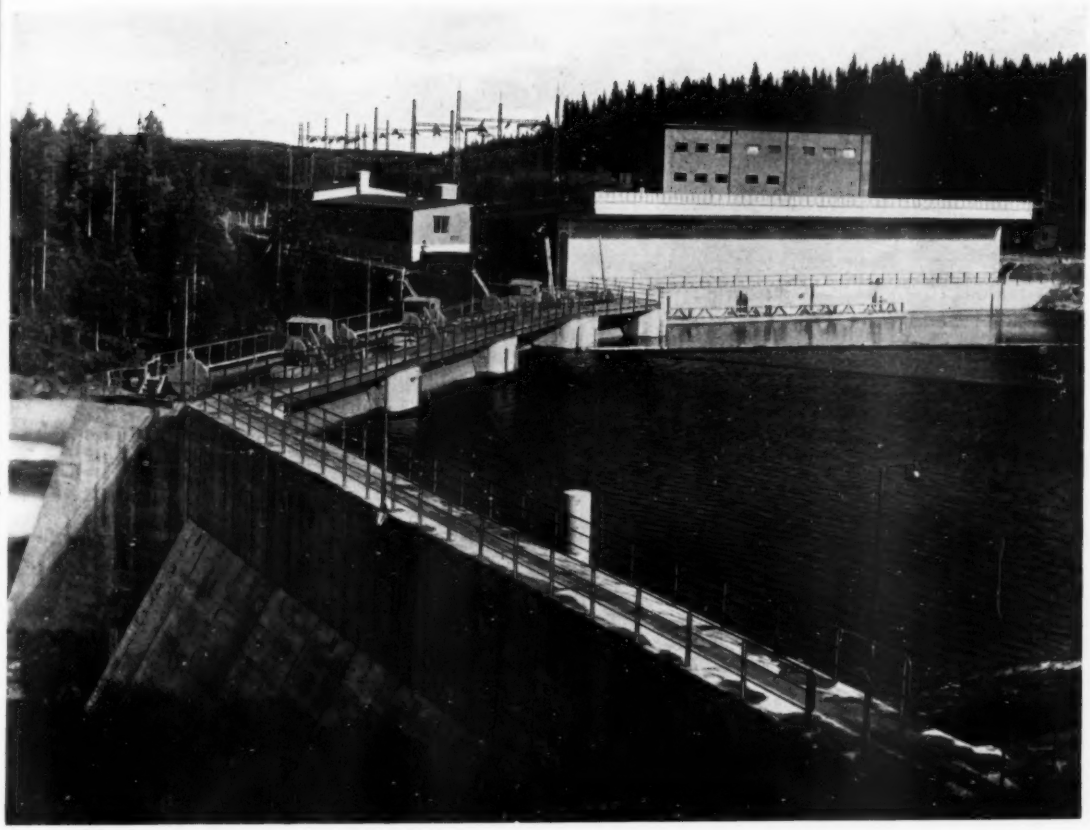

*Fig. 1. Sweden's Water Power resources*

It may be of interest briefly to mention some of the rivers of greatest importance from the power production aspect; and to touch briefly on the larger hydro-electric plants. Farthest north runs the Luleälv (*älv* = river, and *älven* = the river) with a water flow at the State power station at Porjus of 255 cubic metres a second (annual average). The capacity of this station is 135,000 kW at a head of 57 metres. Further down the river lies the development of the mighty rapids at Harsprånget which, when fully harnessed (probably in 1952), will be the largest power project in the country, having a total capacity of 290,000 kW. In the centre of Norrland is the Indalsälven river which is now the most important power resource of Sweden. Among the power stations it supplies are Krångede, with a capacity of 210,000 kW at a head of 60 metres; Stadsforsen, due for completion in 1951, with a capacity of 130,000 kW; Hölleforsen where 126,000 kW plant is scheduled for operation in 1950-52, and Järpströmmen having a capacity of 115,000 kW at a head of 60 metres. A river which is growing in importance from a hydro-electric point of view, is the Ångermanälven. On one of its tributaries there is Hjälta which is scheduled for completion in 1952, when its capacity will reach 180,000 kW. Among other rivers in Norrland of great importance to power production are the Ljungan and Ljusnan.

In Northern Svealand there are several plants on the Dalälven river. The principal rivers in Western Sweden are Klarälven and the Götaälv, which are respectively north and south of Vänern. At Trollhättan on the Götaälv river where the water flow is 502 cubic metres a second, and the head is 30 metres, lies the oldest major State hydro-electric plant constructed in 1910. A later station nearby was started in 1942, and the total capacity of the two is 220,000 kW. For the south of Sweden the river Lagan forms the most important water power source.

Because so great a part of the harnessed water power is situated in Norrland, where the demand is slight, and the consumption of electric energy is larger than the power resources in the southern provinces, it is necessary for power to be transmitted in bulk over long distances from the northern to the southern parts of Sweden. At present five main transmission lines are operating at 220 kV. New lines are under construction and in the near future, when the 220 kV system is extended to Malmö in Scania, the total length of the lines in this system will be 900 km. Lines are also being constructed for 380 kV A.C., while for distribution of power in different districts voltages of 132, 77 and 55 kV are employed.

The total amount of electrical energy generated in Sweden in 1946 was about 14,200 million kWh, and of this sum more than 95% was produced by hydro-



*Järpströmmen power station recently completed*

electric power stations. In the following statistics reference is made to 1946, not 1947 (the latest figures available), because the scarcity of water made it a highly abnormal year.

Available world statistics show that Sweden occupied fourth place—at least in 1944-45—among all countries in respect of its production power from hydro-electric resources, those preceding it in the list being the U.S.A., Canada and the U.S.S.R. At the present time it is thought that France, Italy and Norway have water power production equal in size to that of Sweden, but for the period after the war comparisons have been difficult because of the disturbances in the regular flow of statistics. While Table I showed the plant capacity in the previous years, and that projected for the immediate future, Table II indicates production in kWh of electrical energy from both hydro-electric and thermal sources.

TABLE II
Production of electricity

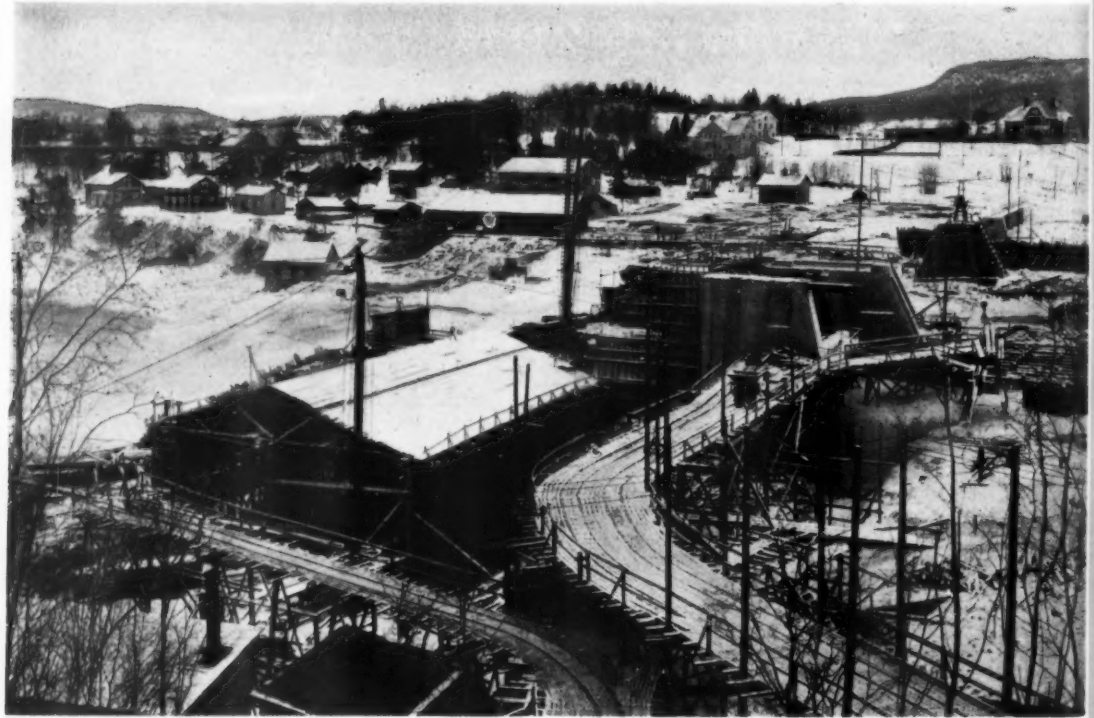
| Year | Hydro-electric | | Thermo-electric | |
|---|---|---|---|---|
| | Million kWh | Per cent. | Million kWh | Per cent. |
| 1939 | 8125 | 89.7 | 929 | 10.3 |
| 1940 | 8042 | 93.3 | 582 | 6.7 |
| 1941 | 8703 | 95.5 | 414 | 4.5 |
| 1942 | 9230 | 94.2 | 565 | 5.8 |
| 1943 | 10714 | 97.1 | 321 | 2.9 |
| 1944 | 12103 | 97.4 | 324 | 2.6 |
| 1945 | 13151 | 97.1 | 389 | 2.9 |
| 1946 | 13523 | 95.3 | 674 | 4.7 |

It will be seen that in 1940, when Sweden was isolated from oversea markets, the result was a moderate decline in power production; but this decline soon changed to an increase, and the rise in the period 1940-46 was not less than 65%. The table also clearly shows that in the years 1943-45, the thermal power stations did not produce more than 3% of the total sum.

In 1946, a certain shrinkage of the water supply began to be noticeable. New construction work on hydro-electric plants at that time was not at a high level, while the import of coal and fuel oils improved considerably; these factors contributed to an increase in thermal electric production. The year 1947 was also characterised by the extraordinarily small precipitation of water, and the scarcity of water for hydro-electric plants was seriously aggravated. At the end of October of that year, the reservoirs were filled on an average only to about 56% of their capacity. Hydro-electric output decreased in 1946-47 by more than 12% to 11,860 million kWh. Thus the thermal plants had to be utilised to the utmost degree, and their production in 1947 reached the extremely high level of 1,600 million kWh—138% more than 1946, and about 12% of the whole power production. The year 1948 has seen a considerable increase in water supply, and at the end of October the reservoirs were filled to about 71% of their total capacity.

The number of units of electrical energy sold per head of the population in Sweden is rather greater

*The Hammarforsen Station, which has an output of 53,000 kW*



*The station on the Indalsälven during construction*

than in the U.S.A. and more than twice as high as in Great Britain. This does not imply, however, that the electrification of the country has been completed; on the contrary, there are several rural districts, generally in remote areas, which are still lacking in electrical facilities. The work on rural electrification continues, and it is hoped that the bulk of the projects in hand will be completed in a few years. The large industries are obviously the greatest consumers of electrical energy, receiving about 70% of the total.

Energy consumption in Sweden is classified under the headings shown in Table III.

TABLE III

MILLIONS OF kWh

| Year | Large Industries | | | Domestic, shops, offices, etc. | Railways and tramways | Used at Power Stations |
|---|---|---|---|---|---|---|
| | Electric Boilers | Electro-chemical and thermal purposes | Other uses | | | |
| 1939 | 318 | 1416 | 4205 | 1214 | 707 | 83 |
| 1940 | 409 | 1330 | 3600 | 1231 | 784 | 75 |
| 1941 | 407 | 1421 | 3514 | 1422 | 869 | 100 |
| 1942 | 269 | 1546 | 3898 | 1547 | 946 | 120 |
| 1943 | 622 | 1882 | 3944 | 1771 | 978 | 105 |
| 1944 | 1096 | 2051 | 4304 | 2030 | 1040 | 109 |
| 1945 | 1244 | 1983 | 4877 | 2353 | 1092 | 114 |
| 1946 | 749 | 1949 | 5532 | 2582 | 1180 | 136 |
| 1947 | 256 | 1878 | 5417 | 2713 | 1223 | 133 |

The first three columns together represent the total electrical consumption of the large industries. In 1946 these figures amounted to 8,230 million kWh. For the year 1947 this total declined by over 8% to 7,551 million kWh.

The total consumption of electrical power by all industrial undertakings included in the statistics of industry issued by the Swedish Board of Trade amounted in 1946 to 8,277 million kWh. Table IV shows the consumption by the most important branches of Swedish industry:—

TABLE IV

| | Million kWh | Per cent. |
|---|---|---|
| Wood industries ... ... | 2,624 | 31.7 |
| Iron and steel works ... | 1,495 | 18.1 |
| Electro Chemical Industry | 733 | 8.9 |
| Workshops ... ... ... | 543 | 6.6 |
| Mines ... ... ... | 301 | 3.6 |
| Metal works ... ... | 280 | 3.4 |

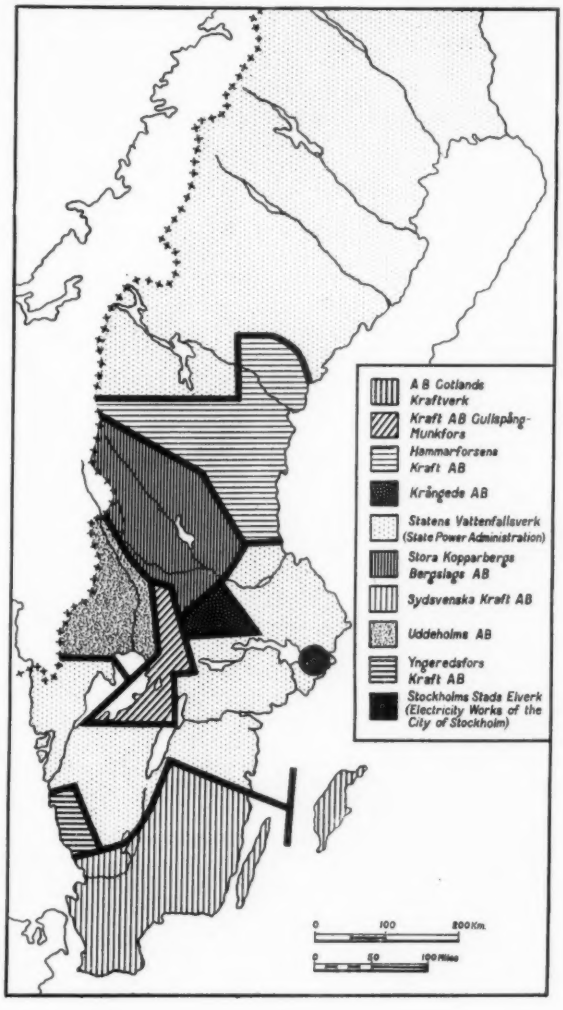
These six branches alone represent nearly three-quarters of the total consumption of all industry. Among the wood industries the pulp mills are the most important, with more than 18% of the total sum.

The energy used by the railways has steadily increased as the electrified network has been enlarged. Although this includes only 40% of the railways by track, about 80% of the traffic is now carried by trains powered by electricity.

In addition to home consumption in Sweden, certain quantities of electricity are used in the power exchange between Sweden and its neighbouring countries, mainly Denmark. There is usually a Swedish "export surplus" of 100 to 200 million kWh a year, but the shortage of water in Sweden lately has made the power balance nearly equal.

It will be seen that the total demand for electric power in Sweden has increased from 7,429 million kWh in 1940 to 12,128 million kWh in 1946. The shortage of water in 1947 caused certain restrictions in consumption, which still exist to some extent; but in the next few years the need for electric power in Sweden is expected to increase at the rate of about 1,200 million kWh a year. In spite of the

*Fig. 2. Distribution areas of the largest power enterprises*



*Pipeline to the Röttle station at Gränna, near Lake Vättern*

progress in harnessing water power it is probable that for the low water periods, which occur principally during the winter months, there will be a certain deficit of hydro-electric energy for some time to come.

The capital invested in the Swedish water power plants during the period 1901-47, was about 1,140 million kr. (approximately £80 million at the present rate of exchange). In this figure the cost of lake regulation is not included; but for the period 1938-47 it amounted to about 42 million kr. (approximately £3 million). For the last ten years statistics have been available of the capital investments in different industries, among them the power plants. They are given in Table V, together with an index number showing variations in the wholesale price level.

TABLE V

| Year | Invested capital in power plants | Wholesale prices Index numbers |
|---|---|---|
| | Mill kr. | |
| 1939 | 85 | 100 |
| 1940 | 99 | 127 |
| 1941 | 111 | 150 |
| 1942 | 125 | 164 |
| 1943 | 128 | 170 |
| 1944 | 107 | 170 |
| 1945 | 96 | 169 |
| 1946 | 163 | 162 |
| 1947 | 225 | 173 |
| 1948 (9 mths) | 259 | 185 |

It should be noted that the power plant construction work undertaken by industrial concerns for their own use is not included in the above figures; but both hydro-electric and thermal power stations are involved in the investments, while for the years 1939-42 gas works and water works are also included. The figures given for 1947, and particularly for the nine months of 1948, are only provisional. The reduction in construction work at the end of the war is clearly indicated.

In the field of power supply there has been for many years a close collaboration between the State, municipal authorities and the private companies. These categories are responsible for 40%, 6% and 54% respectively of the total energy production. There are about 3,500 retail distribution undertakings, of which 2,180 are distribution associations ("Co-operatives") chiefly operating in rural districts. The municipal undertakings number only 170, but have on an average a few thousand consumers for each undertaking, compared with a few hundred for the "co-operatives." The distribution areas of the largest power enterprises are shown in Fig. 2.

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**Sir Ben Lockspeiser** — The King has approved the appointment of Sir Ben Lockspeiser, M.A., M.I.Mech.E., to succeed Sir Edward Appleton as secretary of the Department of Scientific and Industrial Research. Sir Ben Lockspeiser, who will take over on May 1, is a member of the Scientific Civil Service and has risen from the lowest grade to this most important executive post in Government science.

# Upper Nile Projects

The Owen Falls and Allied Schemes are discussed by our Special Correspondent in relation to a more ambitious plan requiring international co-operation.

*La Grande Bretagne et l'Egypte se sont mises d'accord en vue de régler le Nil; un plan complet et détaillé d'aménagement pourra être entrepris, une fois obtenue l'approbation de la Belgique et de l'Ethiopie. Le projet d'ensemble comprend le barrage du Nil Blanc et du Nil Bleu à leur sortie des lacs Tana, Victoria et Albert, ainsi que la construction de bassins de retenue tel que celui d'Assouan sur le cours principal du Nil. Le plan permettra un développement important de l'irrigation et de la production d'électricité, au grand bénéfice de tous les pays intéressés. L'article çi-dessous traite du projet des "Owen Falls," sur le lac Victoria, l'un des grands travaux prévus.*

*Los Gobiernos de la Gran Bretaña y de Egipto han llegado a un acuerdo y se está negociando la aprobación de Bélgica y de Etiopía para la regulación de las aguas del Nilo con miras a iniciar un proyecto de desarrollo comprensivo. El proyecto completo comprende la construcción de presas del Nilo Blanco y del Nilo Azul al salir de los Lagos Tana, Victoria y Albert; y la construcción de más pantanos como el de Assuan sobre el Río Nilo principal. Esto permitiría riegos y la generación de fuerza motriz en gran escala, lo cual sería de gran beneficio para todos los países interesados. En el siguiente artículo se discute el proyecto de los Saltos Owen en el Lago Victoria, constituyendo parte de la obra principal a realizar.*

WORK on the Owen Falls water power scheme, designed to develop the waters of the Upper Nile for both hydro-electric and irrigation purposes, is expected to start this summer. Behind the entire project is the extensive development of the mineral riches of East Africa. It is also linked with the recent visit of a scientific mission from East Africa to the United States.

The immediate object of that mission was to study the methods employed by the Tennessee Valley Authority in the manufacture of fertilizers. Large deposits of rock phosphates are known to exist in Uganda and other territories surrounding Lake Victoria, at the northern end of which are the Owen Falls, and it is confidently anticipated that the knowledge gained from the American visit will be applied to the exploitation of these deposits when hydro-electric power becomes available from the Owen Falls scheme. Members of the mission, who were all experts in their respective fields, included Dr. A. J. V. Underwood, industrial consultant in London to the East African High Commission; Mr. H. B. Stent, acting chairman of the East African Industrial Research Board; Dr. K. A. Davies, director of the Geological Survey, Uganda, and Mr. C. R. Westlake, chairman of the Uganda Electricity Board.

Two main conclusions have been reached by the experts investigating the Owen Falls scheme. They are:—

(1). It will make available, both in its initial and ultimate stages, firm electrical energy at a cost which, in many other schemes, is associated with production of off-peak energy.

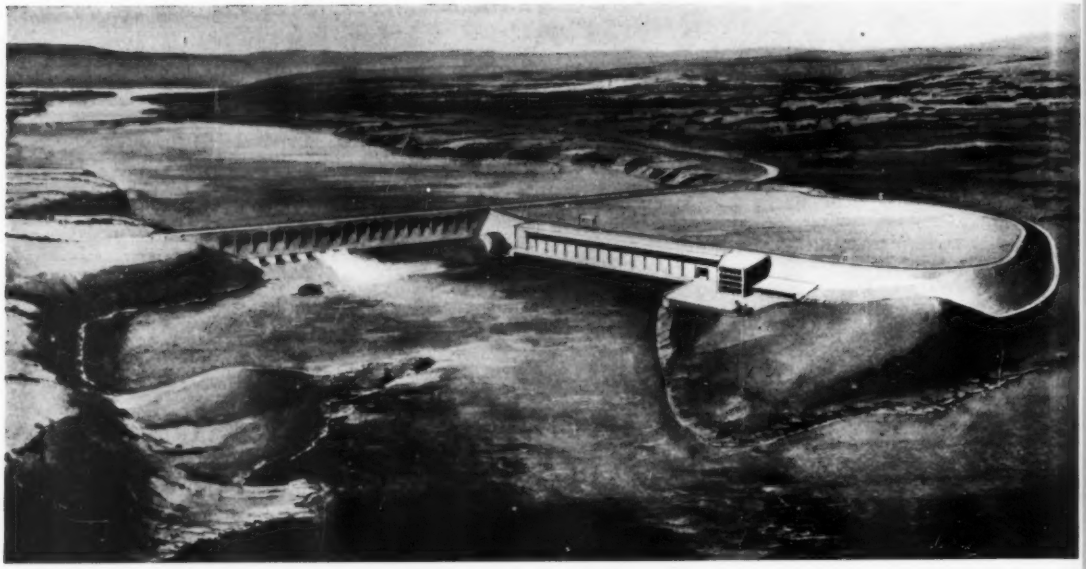
(2). It offers an unrivalled opportunity for raising the standard of living by attracting new industries to the Uganda Protectorate, and by making available a domestic supply of electricity at a reasonable price.

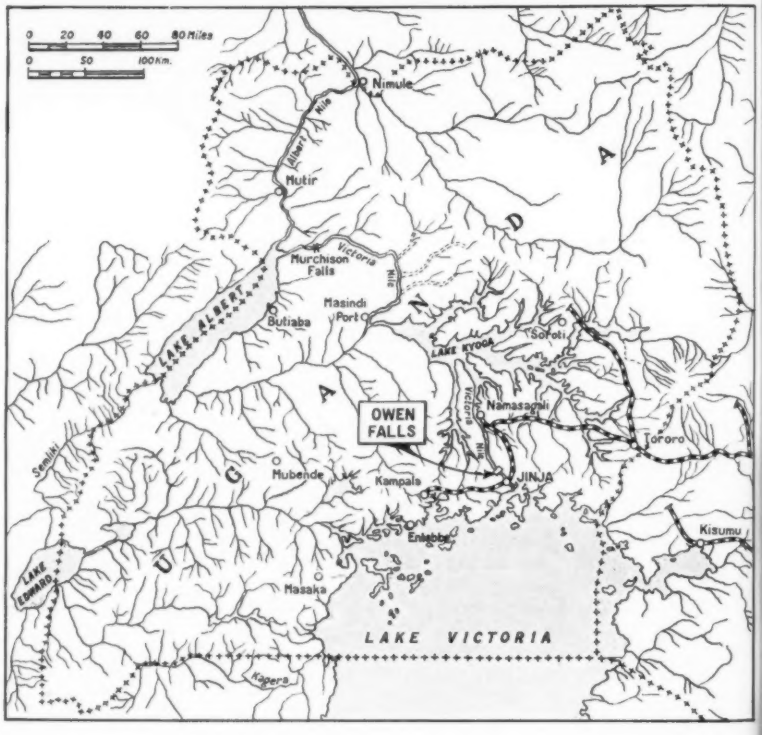
In its 3,000 miles journey from Central Africa to the Mediterranean the Nile traverses many countries; in past years political and economic considerations have caused the potentialities of this greatest river of the African Continent to be neglected. It is hoped, however, that as a result of discussions now proceeding between representatives of the interested governments that the differences will be resolved to the benefit of all.

**Control and Storage**

A report on the Owen Falls project, prepared for the British Colonial Office by two British firms of consulting engineers, Sir Alexander Gibb and Partners and Messrs. Kennedy and Donkin, points out that the water from Lake Victoria (which is 26,000 square miles in extent, or about the size of Eire) passes through the smaller Lake Kyoga to Lake Albert, bordering Uganda and the Belgian Congo. The difference in level between the two main lakes is something like 1,700 feet in the comparatively short distance of 260 miles—only a little less than the fall over the entire 3,000 mile length of the Nile from Lake Albert to the sea. Lake Victoria thus presents an exceptional opportunity for securing complete control of the Nile headwaters, and at the same time offers a simple solution to the problem of providing adequate storage of water, a first priority in view of the increasing population of Egypt as well as of other countries when ultimately the scheme and others associated with it are brought to fruition. On this aspect of the question the report records that average long term discharge of the Victoria Nile is 22,300 cubic feet a second, or about nine times the average discharge of the Thames at Teddington. The investigators here make the point that if the total difference of levels between Lakes Victoria and Albert could be developed for hydro-electric purposes the power available annually would be about 22,000 million kWh, or equivalent to the total requirements of the United Kingdom in 1937.

An important question both for Egypt and the Sudan raises itself here. Other points on the Nile are suitable for hydro-electric installations, but development must





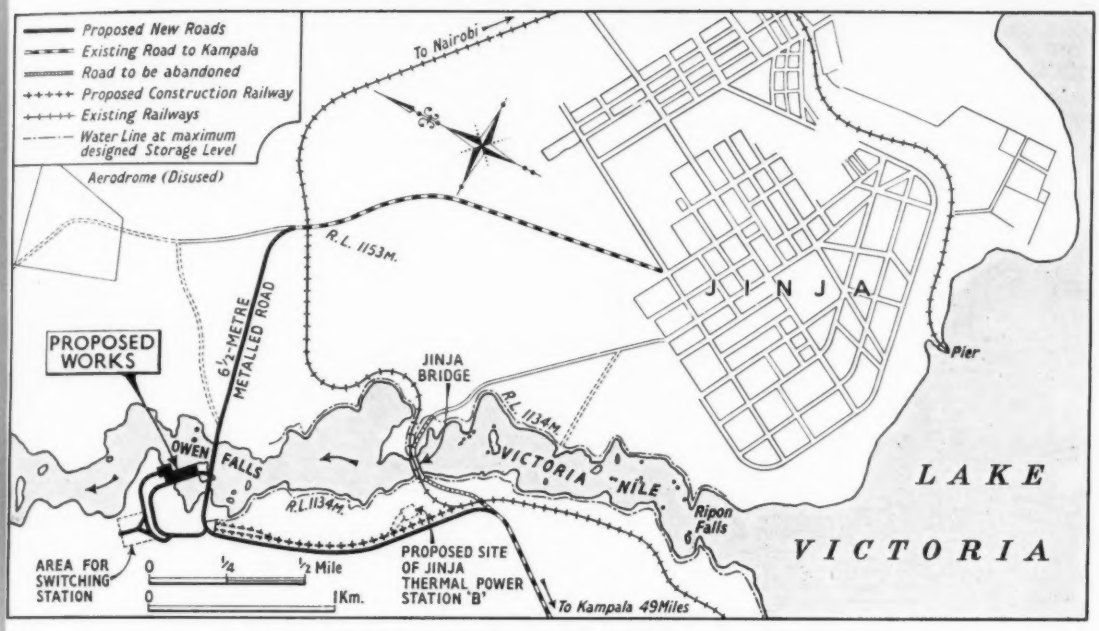

*Above: Drawing of general view showing dam and power station. Right: Sketch map of location of scheme*

involve smoothing out normal fluctuations in the discharge of the Victoria Nile, a problem that has been the subject of much discussion between Egypt and the Sudan, the aim being to establish conditions permitting maximum use of the Victoria Nile flow for hydro-electric purposes, while providing sufficient storage in Lake Victoria itself for use by both countries.

**Station Design**

Design of the falls station, it is urged, should provide ultimately for housing at least eight water turbine driven alternators of 15,000 kW each, and that three of these should constitute the first step. The hydro-electric station, as the accompanying illustrations show, will necessitate a dam closing the eastern channel, and a second dam—incorporating the actual power station—closing the western channel. The former, a mass concrete gravity structure, will be 650 feet long, 66 feet high, and pierced by six culverts controlled by sluice gates permitting release of water from the lake in addition to that used by the power station. The second dam will be about 590 feet long and of similar height. Thus will be provided a head of water available for power purposes of about 60 feet. Turbines of the Kaplan type are recommended in the report.

In the first phase power will be generated at 11,000 volts, to be increased as required for transmission to other parts of the Uganda Protectorate. Cost of the first part of the scheme, including the three 15,000 kW units mentioned, and provision for ultimate increase to eight units, is estimated at £4,160,000, and the complete eight unit project at £7,120,000. If the annual load factor of electrical supply approached 100 per cent., the cost of energy at the station when developed to eight-unit capacity would be 0.841 cents for each kWh. At the annual load factor of 70 per cent. it




*Key plan showing approach roads to dam and power station*

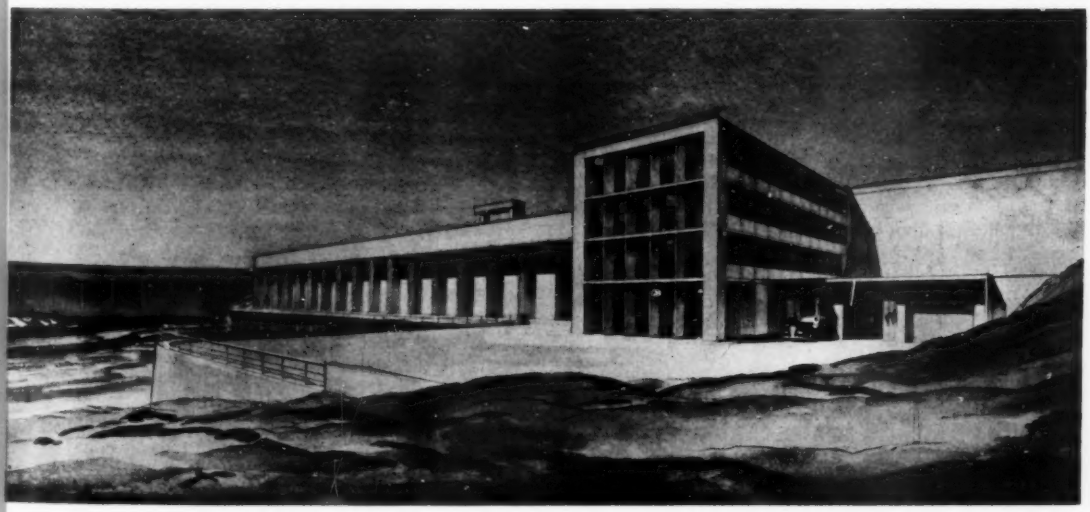
would be 1.203 cents per kWh. During the initial stage, with three units, the estimated cost is 1.71 cents at 100 per cent. annual load factor; 2.45 cents per kWh at 70 per cent., and 2.92 cents per kWh at 50 per cent. (100 c. to a shilling).

**Big Demand Anticipated**

Thus even in the early stages cheap power would be available. Looking to the future the report recommends provision for transmission at very high voltages because the engineers conducting the investigation are convinced that, with the low cost at which power can be made available at the Owen Falls compared with other sources in East Africa, the demand for energy will be far-flung.

The proposals in the report, it is stressed, will not hinder the provision of navigational locking facilities at the falls should these be required for through navigation between lakes Victoria and Albert.

From these considerations it is clear that the Owen Falls scheme can fairly be regarded as the central feature in the further development of the Nile waters over the next quarter or half century. But there are also other proposals of considerable scope for lower sections of the river—the main Nile in the Sudd region and the Blue Nile in Ethiopia. In the latter case Lake Tana might conceivably be transformed into both a storage and power centre by the construction

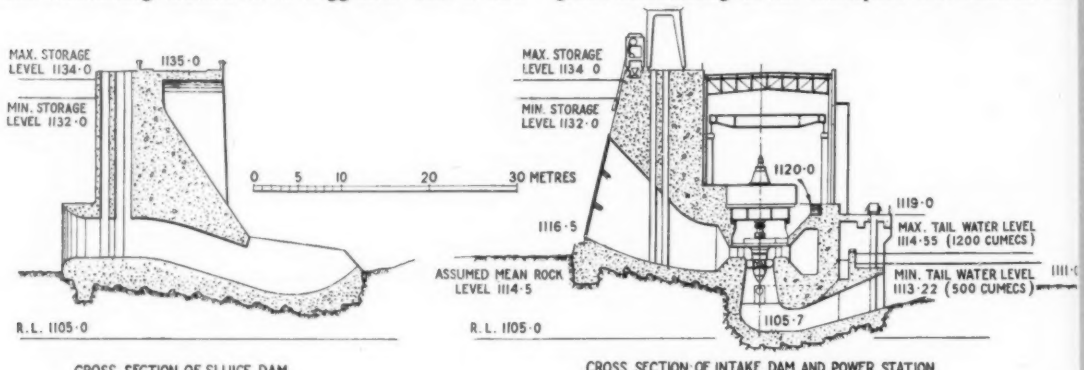


*Artist's impression of the proposed power station*

of a dam at its outlet, as in the case of the Owen Falls at Lake Victoria. In the Sudd area of the Sudan yet another form of conservation works has been put forward. In this region the engineers rightly point to the enormous quantities of water that are lost through the high rate of evaporation. To overcome this real and continuing trouble it is suggested that a new system of canalization of the flow should be undertaken. This would have the important effect of circumventing much of the extensive swampy territory where evaporation is highest, and carry the flow forward for irrigation and other uses. There is little doubt that the Sudan, in particular, would benefit enormously from works of this character, as also ultimately would Egypt, whose constant preoccupation in relation to the waters of the Nile has been that of keeping her supplies of water assured during the prolonged periods of drought. It was this fear, indeed, that was behind the agreement between Egypt and the British Government twenty years ago governing the use of the Nile waters. Fortunately her approval of the present proposals has been secured; but similar agreements concerning plans for the lower reaches of the river have still to be obtained from the Governments of Ethiopia, the Sudan and the Belgian Congo.

There is no reason, so far as can be foreseen, why political and other problems that remain should not eventually be cleared up satisfactorily. No truly progressive leader can fail to appreciate the immensity of the possible gain from the full exploitation of the greatest power potential in North and East Africa, provided the widest measure of co-operation between all interests is secured. That this is so in relation to Egypt, the country most vitally concerned, is evident from the reply given to a question in the House of Lords at the end of February. The question, put by Lord Hailey, asked for information as to the terms on which the Egyptian Government was associated with the Owen Falls scheme, "and the extent to which their association will give them any power to control the type of installation, or the manner in which the power developed by it will be utilised."

The reply, given by the Minister of State for Colonial Affairs (the Earl of Listowel) showed a wider basis of approach than that of the Owen Falls project alone. The Government of Egypt, the Minister affirmed, had indicated agreement in principle "to participate in the comprehensive schemes for utilisation of the waters of the River Nile, including the installation of a hydro-electric power station at the Owen Falls in Uganda." The schemes for the Blue nile, the Minister also emphasised at the same time, must depend for their success on the co-operation of the Ethiopian Government, and the British Government "looked forward to the participation in this great undertaking of the Ethiopian Government and also of the Belgian Government, whose agreement has still to be sought." The exact manner in which these Governments would participate still remains to be worked out. It is established however that the generation, transmission and distribution of hydro-electric supplies within the Uganda Protectorate will be the sole responsibility of the Uganda Electricity Board, recently constituted for this purpose by the Government of that country. The power that will become available will be used for extensive industrial expansion, including the sugar and cotton industries and a cotton textile industry, in Uganda.




*Cross-sections of dam and power station*

**Tenders for Civil Works**

*Our Parliamentary Correspondent* writes:—The British Colonial Secretary (Mr. Creech Jones) announced in the House of Commons in February that tenders for all civil engineering works connected with the dam and power stations for the Owen Falls hydro-electric scheme in Uganda were expected to be in by June, and that it was hoped to have contractors working on the site by September. Substantial quantities of machinery, materials and equipment had already been ordered.

## WELSH VALLEY SCHEME

Objections to the British Electricity Authority's plan to divert the Afan Po River in the Conway Valley will have to be heard before any progress with the plan can be made. In reply to a Parliamentary question by Mr. D. A. Price-White, Conservative Member for Carnarvon Boroughs, who expressed concern at the effect of the proposed diversion might have on public health in the area, Mr. Aneurin Bevan, Minister of Health, said he had not been consulted by the Authority about the proposal. But he was in touch with the Minister of Fuel and Power, who was instructing the Board to publish notices and deposit plans for public inspection so that interested parties could make any representations they thought fit. If objections were made Mr. Gaitskell would consider holding a public local inquiry, at which local parties concerned would be given an opportunity of being heard.

# Hydraulic Turbine Generators

By C. M. LAFFOON *(Westinghouse Electric Corporation)*. American practice is discussed in detail. The use of the probability theory and statistical analysis methods for evaluating different insulations and comparing them and other routine tests are explained

*Les différents types de génératrices à turbine hydrauliques construites en Amérique sont étudiés ici en détail. Les besoins divers de l'industrie demandent des matériels de proportions très différentes, déclare l'auteur; on peut les classer, suivant la disposition des coussinets et des paliers de butée, en deux types principaux qui embrassent toutes les grosses génératrices à turbine hydraulique à entrainement vertical. L'auteur explique l'emploi de la théorie des probabilités et des méthodes d'analyse statistique dans le calcul et la comparaison des isolements.*

*Se discuten detalladamente los métodos prácticos norteamericanos en el diseño de generadores hidráulicos de turbina. El autor indica que las diversas necesidades de la industria exigen grupos de proporciones grandemente distintas; comprenden dos tipos generales reflejados por la disposición fisica de los cojinetes de empuje y guía, los cuales abarcan el campo completo de los generadores verticales de accionamiento por turbina hidráulica. Se explica el empleo de la teoría de probabilidades y de métodos de análisis estadísticos para calcular los diversos aislamientos y para su comparación, describiéndose al mismo tiempo otras pruebas rutinarias.*

IN the U.S.A. hydraulic turbine driven generators comprise a significant *percentage* of the central station generating capacity now installed. Prior to 1920 the installed hydro-electric generating capacity was approximately 3,700,000 kW, of which about 95 *per cent* was privately owned. In the following twenty years the hydro capacity was tripled with the installation of about 7,500,000 kW, of which approximately two-thirds was privately owned and one-third sponsored by government agencies or authorities. In the period from 1940 to 1947 about 3,750,000 kW was installed with roughly 90 *per cent* accounted for by government sponsored power projects.

Based on the projects now under consideration, contracts were placed for approximately 2½ million kW of hydro-electric generating capacity during 1948; it is further predicted that in excess of 1¼ million kW will be added annually in the next four years. With this expansion programme carried out, the total installed hydro capacity will be increased by about 50 *per cent* over the total installed capacity prior to 1948.

The pronounced shift of hydro-electric developments from privately owned enterprise to public agencies or authorities is in a large measure due to the broad range, multi-purpose character of the hydro projects. These large hydro-development projects usually embrace flood control, navigation, irrigation, water supply and the generation of electric power.

In the U.S.A. hydraulic turbines are normally built by companies engaged primarily in the manufacture of this kind of equipment, and the hydro-electric generators are built by the manufacturers of large rotating electrical equipment. There is only one case in which a large manufacturing company builds hydraulic turbines and generators. With the two elements built by different companies, no difficulties of any kind are experienced with respect to development of and responsibility for the performance of the overall unit or its component parts. For most projects, the hydraulic conditions are such that vertical units are required in order to obtain the maximum energy from the water passing through the turbine. For vertical water wheel generators, it is customary practice for the rotating parts of the generator and turbine to be supported by a thrust bearing which is an integral part of the generator.

The hydraulic characteristics of available head, water flow, and the distance of the hydro-electric development from load utilization centres require units of wide range in speeds, ratings, hydraulic, and electrical characteristics. Table I shows the ratings and characteristics of a number of large vertical water wheel generators of recent manufacture.

**Types of Water Wheel Generators**

The varying needs of the industry require units of widely different physical proportions. Two general types of design as distinguished by the physical arrangement of the thrust and guide bearings, cover the entire field of large hydraulic turbine driven vertical generators. One is the "umbrella" type as shown in Fig. 1, in which the combined guide and thrust bearing is located below the generator rotor. This type is particularly well suited for the slow speed units which are large in diameter and short in axial length. The primary advantages of the umbrella construction are: (a) reduction of overhead room to assemble and dismantle the unit during erection and maintenance overhaul, and (b) simplicity of the combined thrust and guide bearing from the standpoint of cooling and minimum amount of piping. The other is the two guide bearing design (Fig. 2) in which the thrust bearing is located above the generator rotor, with guide bearings located above and below the

TABLE I.

| Rating | | | | | Characteristics | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| kVA | P.F. | kW | kV | R.P.M. | Runaway Speed R.P.M. | SCR | $WR^2$ Lbs. Ft. x $10^6$ | Total Thrust Load x $10^3$ | Guide Bearings | Type |
| 20,000 | .90 | 18,000 | 13.8 | 163.6 | 300 | 1.1 | 7.5 | 183 | 1 | Umbrella |
| 38,888 | .90 | 35,000 | 13.8 | 144 | 288 | 1.1 | 22.5 | 395 | 1 | " |
| 40,000 | .90 | 36,000 | 13.8 | 81.8 | 118.6 | 1.0 | 49.0 | 1950 | 1 | " |
| 56,250 | .80 | 45,000 | 13.8 | 120 | 225 | 1.0 | 42.3 | 596 | 1 | " |
| 64,000 | .90 | 57,600 | 13.8 | 120 | 240 | 1.1 | 55.0 | 552 | 1 | " |
| 75,000 | .90 | 67,500 | 13.8 | 150 | 300 | 1.1 | 45.0 | 550 | 1 | " |
| 25,000 | .84 | 21,000 | 13.8 | 128.6 | 350 | 1.25 | 14.6 | 800 | 2 | " |
| 36,842 | .95 | 35,000 | 13.8 | 90 | 180 | 1.5 | 55.0 | 675 | 2 | " |
| 66,700 | .90 | 60,000 | 11.0 | 163.7 | 310 | 1.25 | 36.0 | 650 | 2 | " |
| 37,500 | 1.0 | 37,500 | 11.5 | 400 | 740 | 1.88 | 3.3 | 215 | 2 | Conventional |
| 63,000 | .90 | 56,700 | 13.8 | 240 | 444 | 1.4 | 16.0 | 450 | 2 | " |
| 82,500 | 1.0 | 82,500 | 16.5 | 180 | 320.4 | 2.74 | 105.0 | 590 | 2 | " |
| 108,000 | 1.0 | 108,000 | 13.8 | 120 | 210 | 1.75 | 150.0 | 925 | 2 | " |

*Typical Ratings and Characteristics of Vertical Water Wheel Generators of recent manufacture by Westinghouse Electric Corporation*

generator rotor. This bearing arrangement is used for the high speed generators which have a greater ratio of axial length of the rotor core to its diameter.

The totally enclosed recirculating system of ventilation is generally used for large and medium capacity water wheel generators. The ventilating air is circulated through the circuit consisting of the generator, the air to water heat exchangers, and the duct work by shaft driven centrifugal fans.

The primary advantages resulting from the use of the recirculating system are:

(1) Longer life of the insulation due to absence of foreign material which would deposit on the surfaces of the windings and clog vent ducts;
(2) Reduction of fire hazard by confining the ventilating circuit; thus permitting the more effective use of fire extinguishing equipment, such as $CO_2$ or water;
(3) Reduction of the noise level in the power house, particularly for high speed units;
(4) Warm air can be by-passed from the enclosure for total or partial heating of the station; and
(5) Reduction of the temperature in the power house during the summer months so that working conditions will be more comfortable for the operating staff.

The arrangement of the cooler sections, the number used, and the method of mounting varies and is dependent on the physical size of the generator, the specific requirements of the purchaser or on power house space limitations. Cooler arrangements can be adapted by suitable baffling for bleeding warm air to heat the station. Where warm air is bled from the system for the purpose of heating the station, it must be replaced by clean, filtered make-up air from the station, otherwise the advantages of the enclosed system may be sacrificed.

The enclosed system of ventilation permits the efficient use of $CO_2$ for fire protection. The enclosure is sufficiently tight so that $CO_2$ can be introduced manually or automatically without excessive leakage and gas consumption. The generator manufacturer normally provides $CO_2$ headers and piping details in the generator end winding zones.

**Mechanical and Material Problems**

Many difficult mechanical and material problems are encountered in the design and construction of large capacity water wheel generators due to their low rotational speeds and inherent large physical dimensions and weights. These problems are associated with the generator stator, rotor, and the thrust bearing. Since the diameter of the stator core is very large as compared to its radial depth, it has a very low rigidity factor in resisting unbalanced magnetic pulls, and other magnetic forces resulting from harmonics and sub-harmonics in the stator winding. The design, construction, and assembly of the stator frame must be such that it assists the stator core in maintaining a true cylindrical shape. This means that the elastic characteristics of the frame and core must be reasonably well matched. If the frame is too rigid with respect to the core, axial and radial buckling of the core may occur when wide stator core temperature variations result from fluctuating loads. Although some core troubles occurred from this cause several years ago, the design deficiencies have been corrected and the construction of modern water wheel generator cores is such that reasonably trouble-free operation is obtained regardless of whether the cores are assembled from built-up sections, or the laminations stacked as a continuous circle.

The rotor of large vertical generators consists of (1) a central structure called the spider, Fig. 3; (2) the rim, Fig. 4, mounted on the spider and to which the poles are attached; and (3) the poles, Fig. 5, and coils, Fig. 6. The spider of large generators may be constructed of cast steel or fabricated from steel plates and structural shapes. In either case, particular care must be taken to distribute the mass in the arms and the hub to equalize the stresses. When the fabricated construction is used, the completed structure must be adequately stress relieved by annealing to remove all residual stresses which may be introduced by welding operations. With either type of spider construction a thorough check of materials and workmanship is made with the now available highly specialized techniques of inspection by magnafluxing, X-rays, and the reflectoscope to make certain that the product will be trouble-free in service.

The laminated segmental rim which is obtained by stacking the overlapping laminations in a continuous circle, bolting them tightly together and shrinking the assembly on the rotor spider does not introduce any problem other than one of material testing to be sure the material meets the specifications. This is equally true of the laminated pole assembly.

There is a problem of adequately designing the field coil connections in the interpolar spaces. The field coils are form wound but cannot be manufactured to precise and close tolerances so there is some slight tendency for coil movement on the pole during operation. Very small movement, particularly if it is cyclic, can result in fatigue failure of a rigid field-coil connector. Flexible field coil connexions are now used to provide against this type of failure.

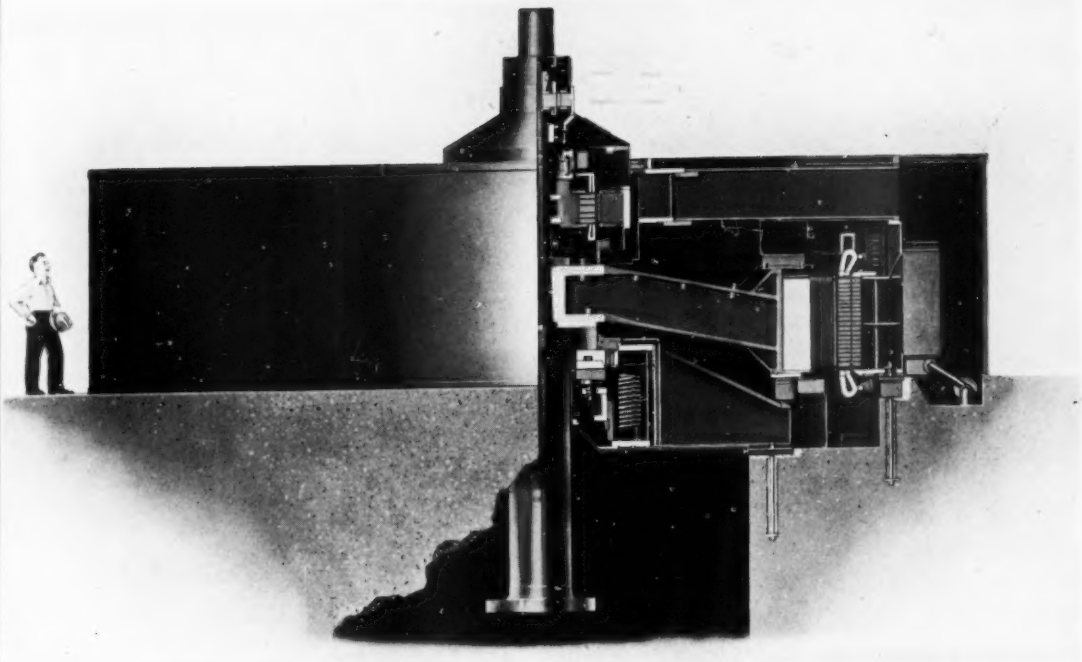


*Fig. 1. Umbrella Generator in cross section*

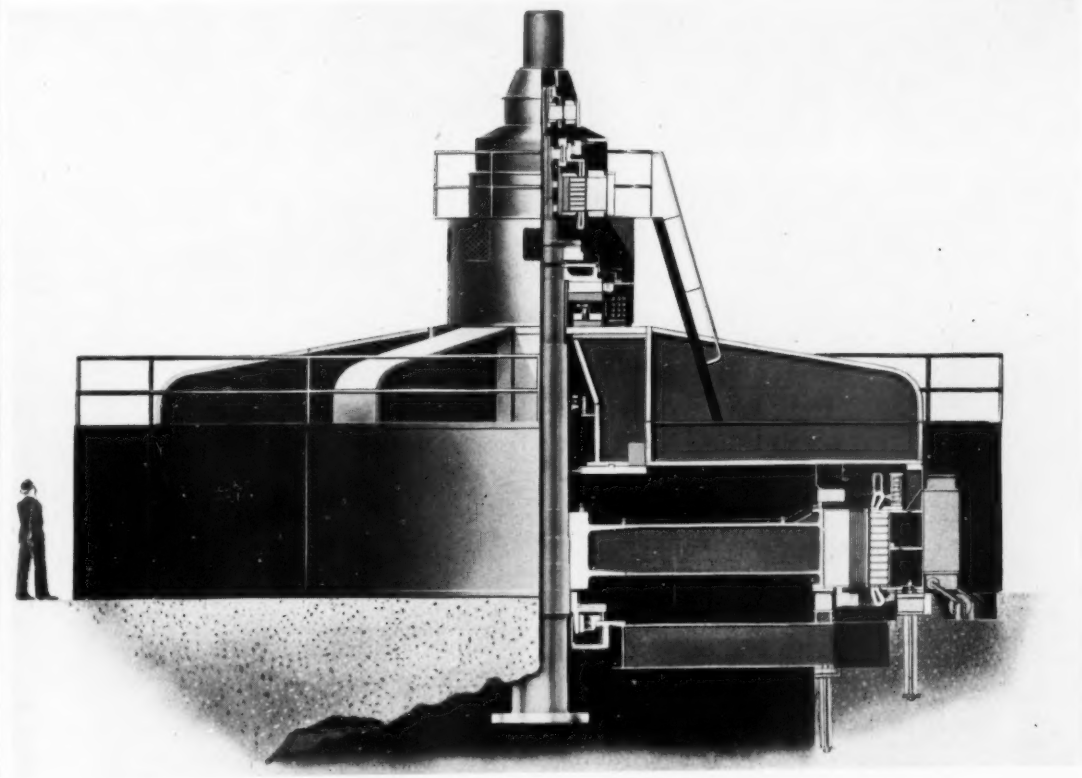
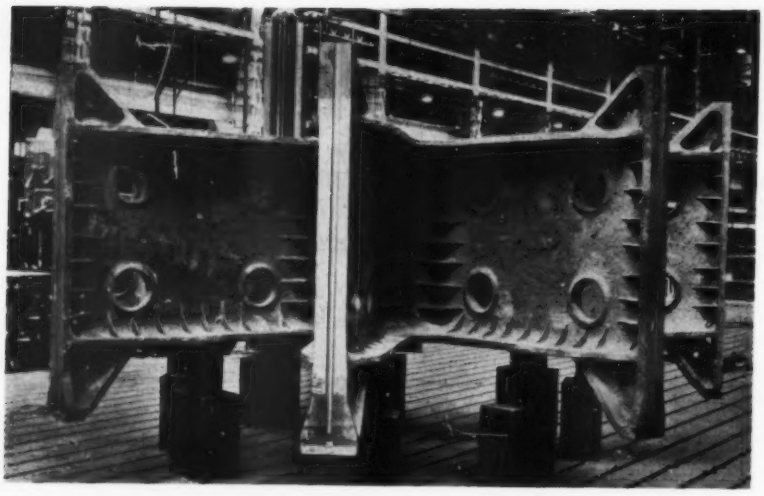
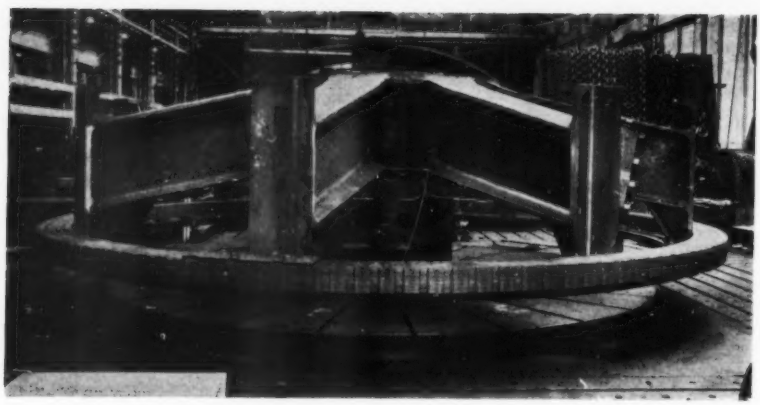


*Fig. 2. Conventional Two Guide Bearing Generator*





**Thrust Bearing Requirements**

The thrust bearing of the vertical hydraulic turbine generator is required to support the combined weight of the generator and turbine rotating members and the hydraulic thrust load. It is present design practice for the rotating element of the thrust bearing assembly to consist of two parts: a thrust runner (Fig. 7) and its thrust block or collar support (Fig. 8). In the case of the "umbrella" type generator, the collar support for the runner is an integral flange of the generator shaft. With the conventional type of two guide bearing generator the thrust collar is a removable piece which is shrunk on and anchored to the generator shaft.

"Starting up" and "shutting down" are the most difficult parts of the running cycle of the thrust bearing. In order to obtain acceptable sliding performance of the bearing, the following construction requirements must be met.

(1) Accurate machining is required on the shaft, thrust collar and the thrust bearing runner;

(2) The surfaces of the thrust bearing runner must be flat, parallel to each other and free of waves;

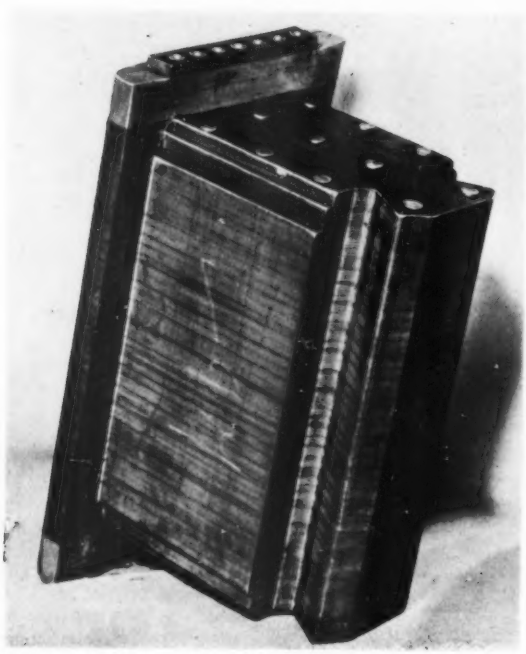
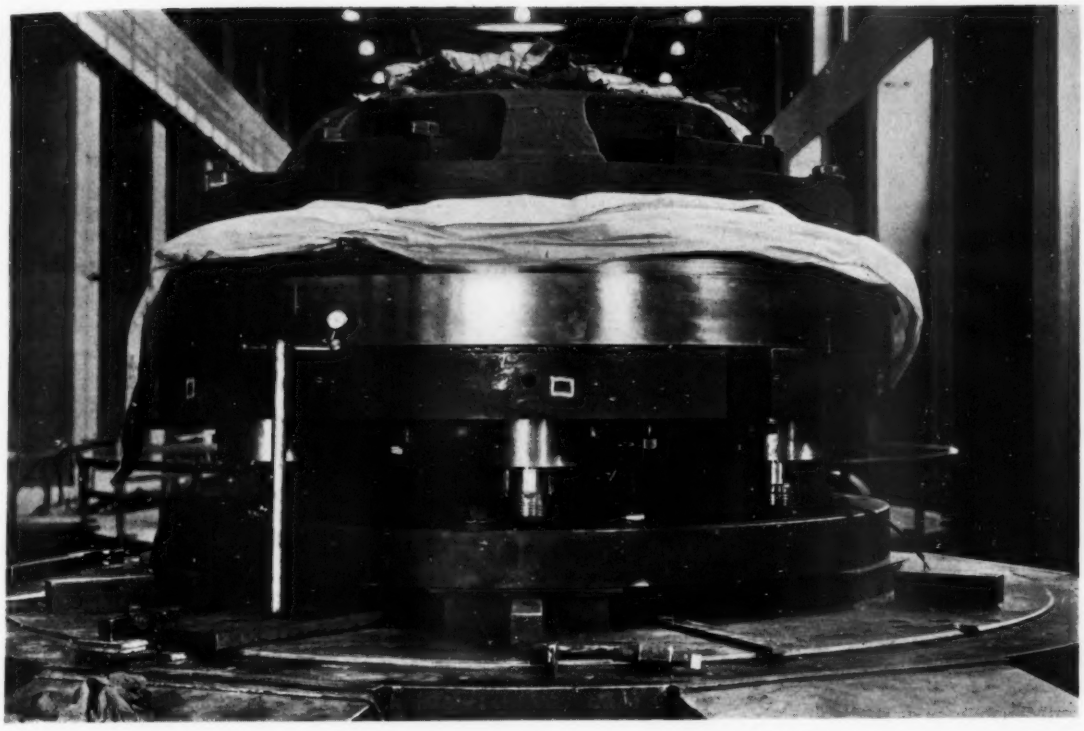


*Fig. 3 (top): Cast steel spider of water wheel generator rotor*

*Fig. 4 (centre): Partially built laminated rim of rotor*

*Fig. 5 (left): Laminated pole piece of rotor*

*Fig. 6 (right): Generator field coil assembly on pole*



*Thrust bearing runner below (Fig. 7) and complete assembly with collar, runner and shoes in Fig. 8 (top)*

(3) The surface of the runner which is in sliding contact with the shoes or pads must have a high quality finish in order to reduce the friction losses during starting up and shutting down;

(4) The sliding surface of the runner in the final assembly must be perpendicular to the axis of the shaft;

(5) The design and proportion of the parts of the bearing must be such that slippage between mating parts due to pulsating elastic deformations are kept to a minimum in order to prevent fretting corrosion.

The machining of the bearing parts to the required close tolerances is done on an accurate precision type of boring mill (Fig. 9), located in an air conditioned room. The smooth, highly polished finish on the runner sliding surface is obtained by a lapping process. The quality of surface finish is determined by roughness measurements with a profilometer type of instrument. Surface finishes of 5 to 12 micro-inches are considered necessary for reliable bearing performance and are readily obtained for all sizes of runners. Equally good finishes have been obtained with runners made from alloy steel forgings or chilled cast iron. Due to the difficulty of obtaining castings free of defects, alloy steel forgings are now generally used.

The metal wear at mating surfaces of thrust bearings has been recognized as a major problem for only a relatively short time. It is most pronounced at the contact surfaces of the runner and the thrust collar. The load distribution on the runner at the plane of the oil film is determined by the number and proportions of the shoes. The pressure is at a maximum at the central section of the shoes and is zero at the edges. The pressure loading waves are fixed with respect to the shoes but move at rotational speed with respect

*Fig. 9. Finished thrust bearing runner on special boring mill*

to the runner. The elastic deformations of the runner resulting from the rotating pressure waves produce a minute slippage motion between the contact surfaces of the runner and the thrust collar, and results in an oxidizing type of wear which has been designated " fretting corrosion."

The frequency of the slipping motion is fixed by the product of the number of shoes and the rotational speed. The amplitude of the motion for a given total thrust load is determined by the maximum value of the pressure wave, and the attenuation factor of the wave at the mating section. Extensive investigations have been made on machines in service, and on large size laboratory models to determine the fundamental causes of "fretting corrosion" phenomena. As a result of the past two years' investigation, it has been determined that fretting corrosion in thrust bearings can be effectively reduced and brought within acceptable limits by:

(a) Increasing the number of shoes to reduce the maximum amplitude of the pressure wave at the sliding surface;

(b) Increasing the thickness of the runner so that a more uniform pressure distribution will be obtained at the mating surface contacts;

(c) Decreasing the elastic deformations by using a material for the runner which has a high modulus of elasticity. (The modulus of elasticity of steel is approximately twice that of cast iron).

**Mechanical Brakes and Rotor Lift**

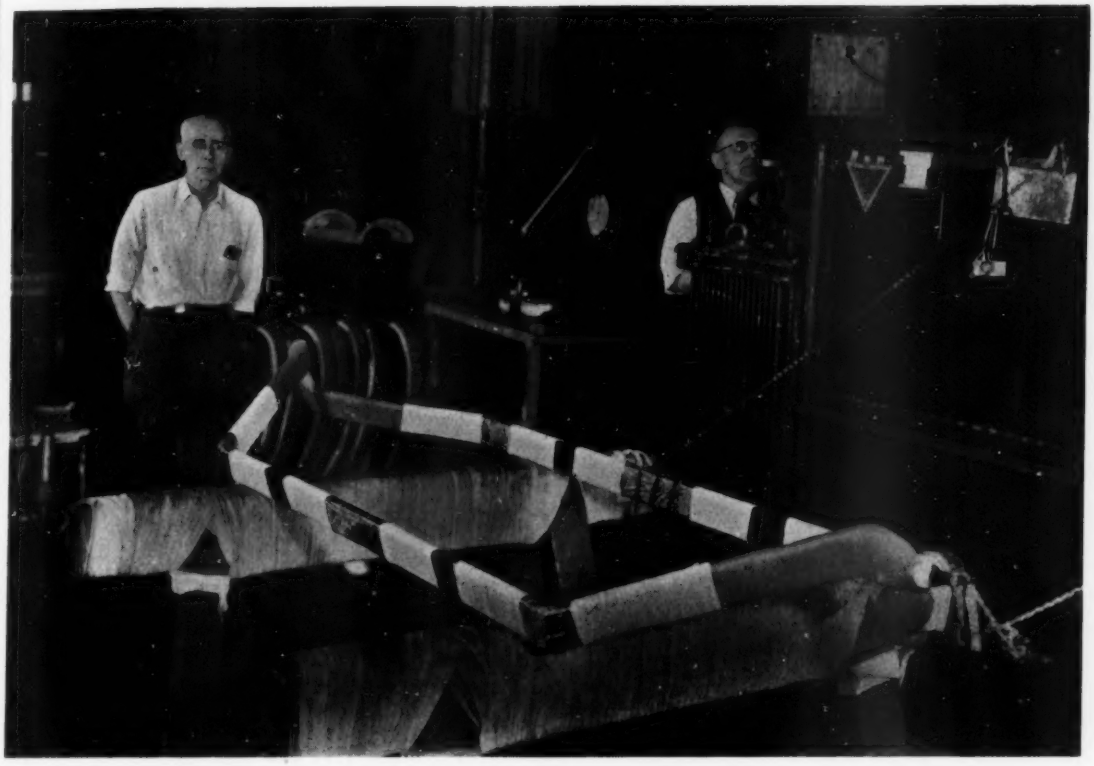
Large vertical water wheel generators of Westinghouse design are provided with a set of combined brake and hydraulic jacks, and these have been used to lift the thrust bearing runners away from the thrust bearing pads in order to build up an oil film between the bearing surfaces before starting the machine.

This method is based on the fact that when pressure is applied to two bearing surfaces separated by oil viscosity restrains its escape and an oil film is maintained for an appreciable time. If the machine is started during this period the starting coefficient of friction will be very low, and solid friction will be entirely eliminated. The scheme provides starting conditions equivalent to those obtained when oil is forced between the bearing surfaces by means of high pressure pumps.

An automatic control scheme has recently been developed and used on some large generators that can be operated from the governor control panel. It permits lifting the rotor with the hydraulic jacks and releasing the jacks very rapidly when starting the machine. Control switches are also provided to allow the jacks to lift the rotor for inspection or maintenance.

**Insulation Development**

Insulation for high voltage machines has special requirements which are in many cases far beyond the needs of the smaller and lower voltage machines. Asphalt bonded mica tape insulations have long been used by the major manufacturers of high voltage generator insulation. In many respects, this type of insulation has given excellent performance. The chief limitations of asphalt bonded mica tape insulation have been physical and it has required considerable operating experience for these problems to become apparent. For example, asphalt bonds are thermo-



plastic and essentially liquid at elevated temperatures. Furthermore, they frequently contain low molecular weight components which become gaseous when heated. At high temperatures this might result in gas pressure on the mica flakes while they float in liquid. Thermal cycling or gas pressure may produce a permanent displacement of the mica flakes as there is no restoring force. Machines which are not conservatively operated are more likely to experience such difficulties as the insulation temperature is significant as well as the degree of differential movement during thermal cycling.

The inherent variability of dielectric strength has made it difficult to evaluate existing insulations and compare them with newly developed materials. Probability theory and statistical analysis methods have been found to be important aids in evaluating different insulations and comparing them. A summary of the method employed in quality control testing of coils will illustrate the manner in which this is done.

Testing individual coils to destruction is the only method of determining the dielectric strength of windings, but unfortunately this renders the winding useless; it has, however, been found that a sampling procedure employing probability theory can determine the dielectric level of a set of coils or winding. This, when coupled with proof-testing of each individual coil, gives positive assurance of an adequate dielectric quality level. In a quality control test procedure a few coils are selected at random from each set of coils manufactured (extra coils being made for this purpose). The test procedure consists of dividing the coil into parts with separate electrodes on the individual parts. These individual parts are then tested

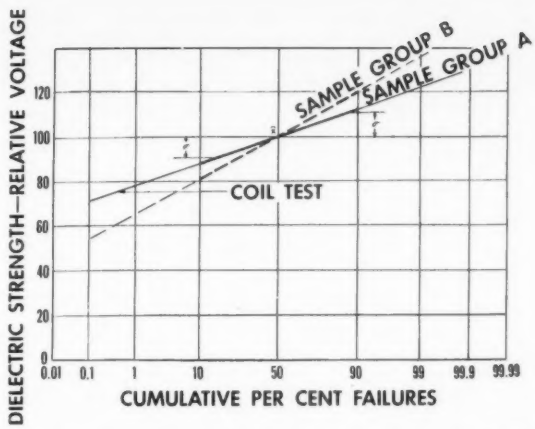
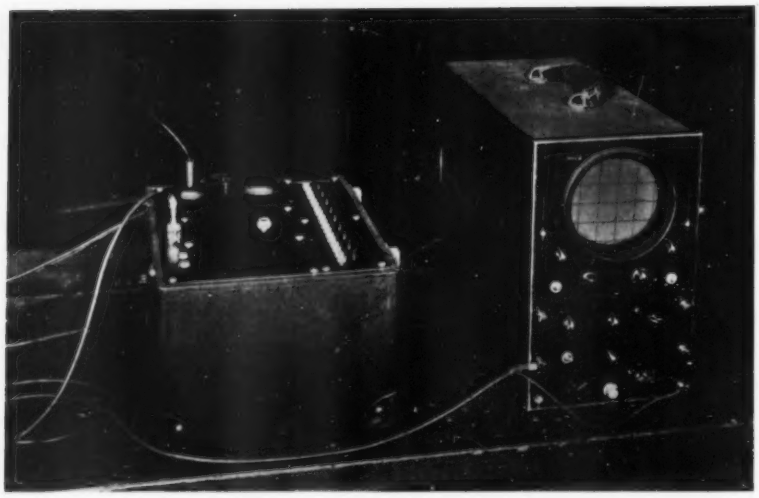



*Fig. 10. High voltage generator coils under test; and probability curve of test results (Fig. 11) below*

to destruction by applying a one minute step by step high potential test until breakdown occurs. A sufficient number of breakdowns are obtained in this manner so that an average and the standard deviation can be calculated. Fig. 10 shows such a quality control test in progress, and it can be seen that there are six separate electrodes on small sections of the coil.

Fig. 11 compares quality control test data from sample coils of two different batches on probability paper. In both cases, the average breakdown is the same (100). For sample group A, shown in full line, the standard deviation (0) is 10. For the sample group



observed on a cathode ray oscilloscope. The test apparatus contains a series resonant circuit tuned to a specific frequency band in which the slot discharges are dominant. The signals are amplified and appear on a cathode ray oscilloscope. If no discharge exists the pattern on the cathode ray tube will be like the left picture (Fig. 13). When slot discharges exist anywhere within the winding they appear as a dancing pattern of considerable magnitude on the oscilloscope. Such a pattern is shown on the right (Fig. 13). The tester contains a simulated coil circuit with an air gap so that a synthetic slot discharge may be produced for the calibration of any discharges which may be seen.

B, shown in broken line, the standard deviation is 15. If both groups of coils were given a proof test of 75, group A would have only 5/10 of 1 *per cent* failure whereas group B would have 5 *per cent* failure—a difference of 10 to 1 for this particular test in number of failures in groups having the same average dielectric strength and only differing in variability.

**Corona Suppression**

Although Coronox has been used by Westinghouse for end-winding corona suppression for almost a decade, it has been a difficult material to control within the limits of coil surface resistivity which are required for satisfactorily grading of potential. But by the application of statistical methods in testing and adjusing batches of materials, as well as the control of material application processes, it has been found possible to reduce the number of Coronox rejects from about 30 *per cent* to less than 3 *per cent*. Slot corona has been eliminated by the application of a semi-conducting material over that portion of the coil. When this semi-conducting surface is in contact with the core, it completely eliminates any slot corona as there is no stress on the surrounding air pockets. This semi-conducting sheath must, of course, be earthed to the core to accomplish its purpose.

Slot discharges contain capacitive current from the semi-conducting sheath and are at a higher energy level than slot corona and, therefore, are more destructive than slot corona. A special electronic tester was developed which can give definite assurance of the existence or absence of slot discharges. This is shown in Fig. 12. The test is made while a high voltage is applied to the winding; evidence of any discharge in the slots is clearly

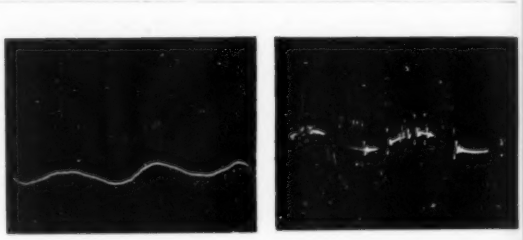
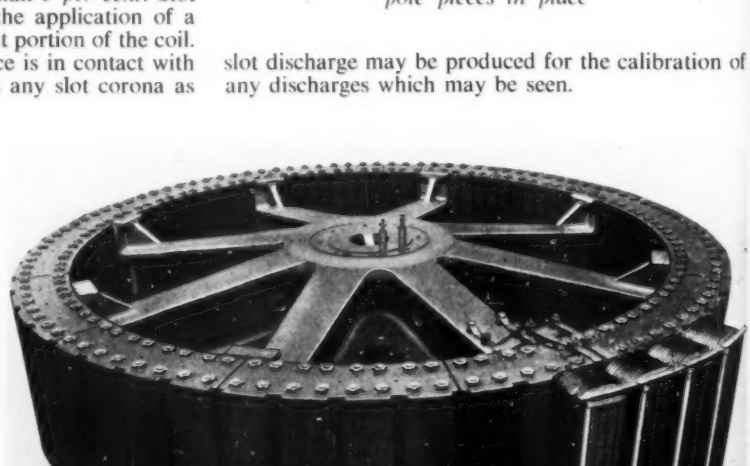


*Fig. 12 (top): Slot discharge test equipment which uses high voltages to locate a leakage path, and centre (Fig. 13) trace observations on a cathode ray tube.*

*Fig. 14 (bottom): Partially assembled rotor with four pole pieces in place*



# Power Plant Construction

By R. R. MINIKIN. The uses of piles, sheet piles, and bearing piles in foundation work for hydro-electric stations. Examples of good practice and some difficult engineering problems.

*La stabilité des fondations est plus importante dans la construction des bâtiments et des ouvrages hydro-électriques que dans toute autre branche du développement industriel, et l'article çi-dessous étudie le pilotage dans la construction des stations génératrices. Il donne des exemples de bonne méthode qui montrent comment l'ingenieur résout certains des problèmes les plus difficiles. Des matériaux manufacturés auxquels l'ingénieur civil fait appel pour triompher des difficultés hydrauliques, ainsi que pour les prévenir, les pilots (déclare l'auteur) sont les plus importants.*

*En toda clase de cimientos para fábricas o establecimientos industriales no hay nada que sobrepase la importancia de la estabilidad de los cimientos de obras hidroeléctricas y este artículo discute los usos de pilotes en construcciones de instalaciones generadoras de fuerza motriz. Se describen muy buenos ejemplos, los cuales demuestran la forma en que los ingenieros de cimientos solucionan algunos de los problemas mas difíciles. Entre los materiales manufacturados que los ingenieros civiles utilizan para contrarrestar las severas condiciones hidráulicas, y también para impedir el que tales condiciones puedan presentarse, el autor hace resaltar la gran importancia de los pilotes.*

THE remarkable progress that has been made in the scientific development of natural resources of power has brought in its train heavy demands upon the civil engineer. He has had not only to adjust many of the old principles of design of works, but has been forced to devise new construction methods to meet the modern requirements: and in no branch of civil engineering is this more in evidence than that connected with foundations. In the past, the attention given to the foundations of all types of structures was perfunctory. They were the buried part of a building; out of sight, unimpressive, and regarded as an item of unfortunate necessity and unproductive expense. It was not unusual for sites of works to be selected, plans of elaborate buildings to be prepared and, indeed, contracts let, before any but a cursory examination had been made of the ground load-bearing capacity. Naturally, this led to heavy expense on sites where the foundation value of the ground, from one cause or another, was eventually found to be of poor quality.

The advent of soil mechanics has now brought about an awareness of the structural importance of foundations, and sub-foundations; which, if not yet recognized as an art of equal importance to that of architecture, or structural engineering, is rapidly pressing its claims to become so established. The eminent professors, scientists, and the literature, now associated with foundation problems are sufficient indications of the modern trend.

In no department of industrial development are the buildings or works more dependent upon stable foundations than in hydro-electric plants: intakes from natural lakes, dams of artificial reservoirs, surge tanks, turbo-machine foundations, pump houses, pipe line supports, canals, outfalls, and spillways, all call for special treatment. Most of the recent schemes of hydro-electric development are situated in mountainous regions where rock sub-foundations lessened the necessity for expensive foundation works, nevertheless they were not entirely eliminated. There are, of course, hydro-electric schemes, and constructions, in lower regions where the foundation works are of paramount importance, as for instance, in the hills of Hyderabad and Madras; Severn Barrage; Bonnington and Stonebyres stations, utilizing the waters of the river Clyde; and all stations sited on the borders of lakes or rivers.

To the electrical engineer water is a valuable fuel (*la houille blanche*, as our French colleagues would say), but to the civil engineer dealing with foundations it is the *bête noir* of his constructional activities; its presence in soils, its power in mass, and head, its insistence in filling voids, its urge of travel; and its fury under concentrated wind action over extensive surfaces, make it a formidable antagonist to control or check.

Of the manufactured materials which the civil engineer calls to his aid to counter severe hydraulic conditions, and also as a preventive against such conditions arising, the most important, and almost indispensable, are piles; sheet piles, and bearing piles. Generally speaking, sheet piles are mostly used as temporary aids to construction; as water seals, earth retaining walls, etc.; and bearing piles are used as permanent load supporting members of a structure. It does not follow that this is always the case, for, given the design, both may be used for any purpose of support. However, our purpose here is mainly concerned with sheet piles, of which the several excellent types manufactured in this country have achieved a world wide fame for reliability of material, and flexibility in use.

Let us take a few examples of good practice showing how the foundation engineer solves some of the more difficult problems. Several large fresh water lakes, or seas, provide a source of power for nearby districts at lower level, and others, where the water is not only drawn off for power but is also utilized after power use to supply irrigation canals for the

surrounding country. A remarkably fine example of resourceful engineering in the construction of a deep water intake was that carried out by the Toronto Authority in Lake Ontario. Neglecting the several important considerations affecting the siting of the intake, the direct relevant conditions, that may equally well apply to several schemes of water power now being considered for different parts of the world, are the hazards associated with frazil ice; that is, the thin sheet ice which wave action breaks up and wind causes to accumulate in quantities; and anchor ice, which forms on the intake itself, by the drawing in of ice cold water.

To avoid choking by these causes and gain the advantage of a lesser variation in the temperature of the intake, the intake was located in deep water fifty feet below normal surface level. From that point of intake a trench, 4,200 feet long, was dredged on the lake bed towards the shore, to house an eight feet diameter pipe at position A (see Fig. 1), which was

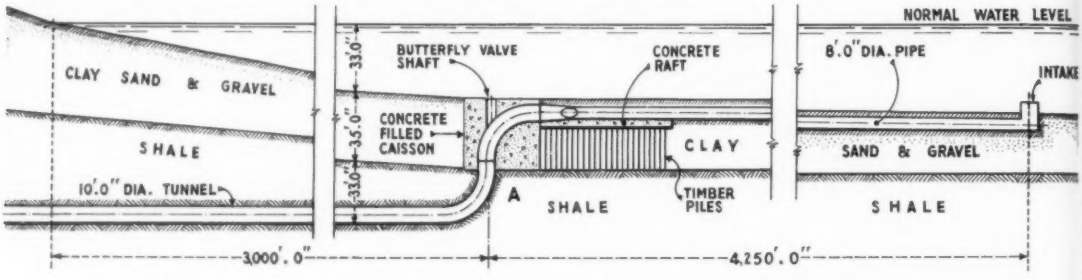



*Fig. 1. A fine example of resourceful engineering by the Toronto Authority*

about 3,300 feet from the lake shore the eight feet diameter pipe connected to one branch of a four-way junction piece; the other two branches were blanked off for future extension. The main branch of the junction piece was connected up to a single ten feet diameter pipe bend of 90 degrees which was turned into the lake bed, and then, by another shoreward right angled bend entered a ten feet diameter tunnel, which was driven horizontally through shale rock to the shore. Now the neatness in which this job was carried out at a total depth of 100 feet below the water surface is the important point. A steel caisson 35 feet in diameter and 34 feet high was sunk in position by the pneumatic compressed air method: a connecting portion of the main branch of the junction piece was fabricated integral with the side of the caisson. When the toe of the caisson was sufficiently anchored into the shale bed, it was efficiently sealed, and the air pressure released. From now on, all excavation through the rock to link up with the shore tunnel was carried on in the open; that is, without air pressure; pneumatic tools being used. The four way junction piece, fabricated of mild steel and weighing about 250 tons, was carried on a mattress of plain concrete 3 feet thick laid on a timber grid supported by timber piles at 3 feet centres driven through the sand, gravel, and clay layers to rock. The heads of these piles were cut at 45 feet below water level, and the concrete mattress was laid by the tremi method.

Dam sites, in mountainous regions, are frequently located in a rocky throat of a valley through which, in summer, there flows a trickling stream. In winter, however, this stream more often than not becomes a raging torrential river. Of course this is to be expected as that was one of the reasons for the construction of the dam. On the flanks of the valley, and in summer, construction work for the dam can go ahead with more or less freedom from elemental interference, but as the verges of the water course are reached there must be some protection from the great violence of the water during maximum flow. This protection usually takes the form of a mild steel sheet pile cofferdam. Now the obstruction to the natural water course created by the cofferdam occasions an added violence of torrent, when in spate, as for example at the Clunie Dam, Scotland, where the upstream bulkhead of a double row of Appleby-Frodingham steel sheet piling was assailed by a turmoil of broken waves, which, in rushing through the narrowed section of the stream bed, caused terrific surges. A single row of Larssen sheet piles formed the downstream wall.

The photograph of the Clunie dam (Engineers—Sir Alexander Gibb & Partners; Main Contractors—George Wimpey & Company Ltd.) in course of construction, Fig. 2, shows the river in a more quiescent state after a raging torrent which reached to within a few inches of the top of the sheet piling. The driving of the sheeting for this cofferdam was rendered difficult by the quantity of large boulders encountered in the bed. This necessitated special sealing devices and bracings to ensure watertightness and stability. The upstream double wall of sheeting was rubble filled, and linked up with the river bank by the wall of concrete bagging shown in the left-hand bottom corner of the photograph. This double wall was stoutly braced and split into compartments with transverse sheeting. The downstream wall was a single line of sheeting backed with a berm of rubble.

Almost without exception dams of concrete construction are founded on rock. The method of protection from flood waters with slight variation follows the scheme shown in Fig. 3. A double wall earth filled cofferdam ABCD of steel sheet piling of adequate scantling is driven around the site of the foundations to one side of the valley. The clearance between the inside sheeting and the ground line of the foundations is usually thirty feet minimum, depending upon the manner of construction of the walls. If the impeded water course is a slow moving shallow stream then a single sheet wall supported inside with an adequate berm of excavated material, and tied back to anchorages, may be used. In such cases the clearance will then depend upon the depth of foundations below the original bed of stream and the width

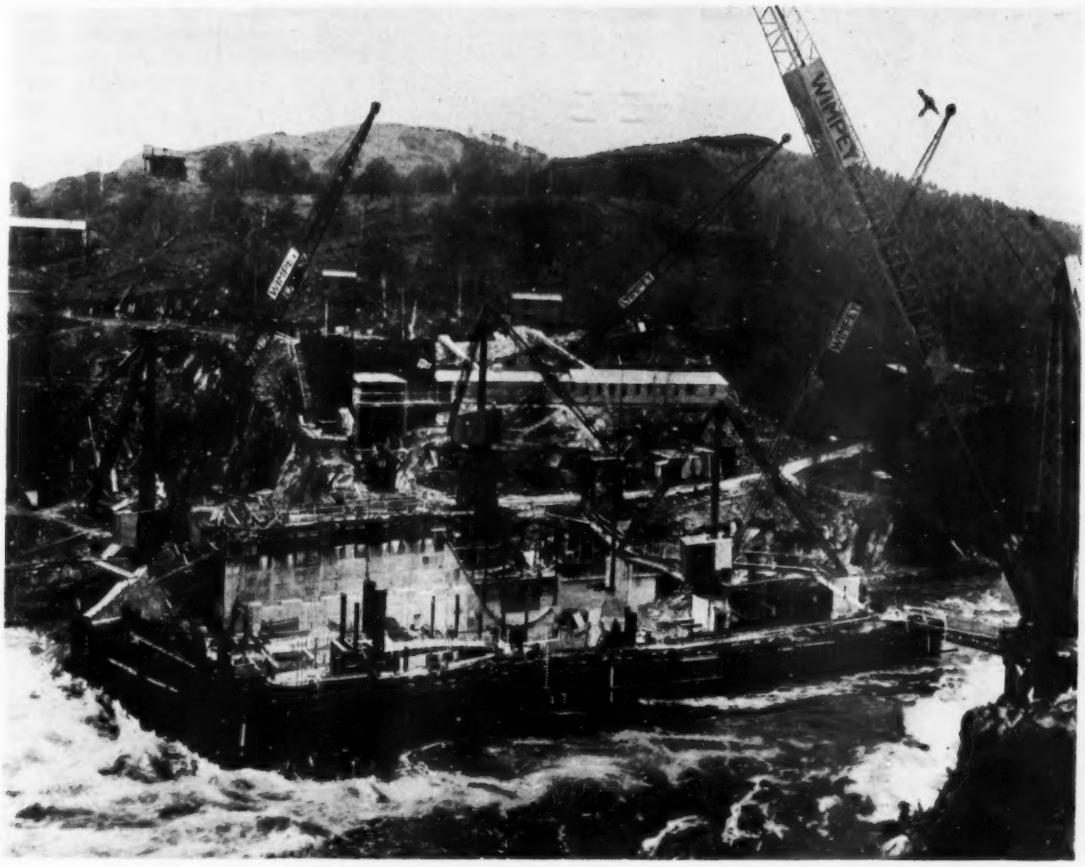



*Fig. 2. The Clunie dam during construction; the torrent rose to within a few inches of piling top*

of berm. If double sheeting walls are used, it is advisable to divide the enclosed space into cellular compartments by driving transverse bulkheads between the walls. Where the sheeting is driven through soil, or even when back filled, the grains of soil which enter the clutches increase the friction to such a degree, and provide so high a shear resistance, that the series of sheets act as one, giving the necessary rigidity and security to the wall, and limiting any damage that might occur to the sections affected.

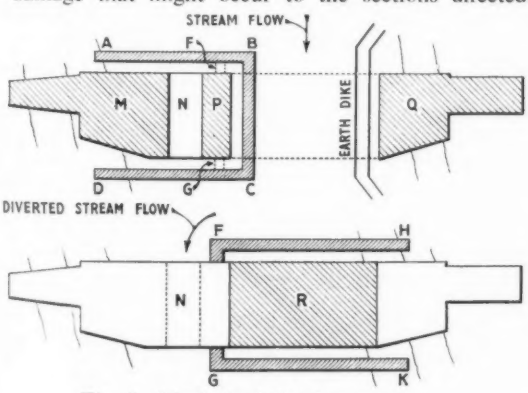



*Fig. 3. Method of flood protection*

The first stage of the dam foundations MP is then constructed to a height above the maximum water level; the channel N being left at a suitable level to carry the stream waters, when the second stage of the construction is under way. The second stage is started by driving sheeting in the positions F and G and sealing the ends against the dam section P. Then after withdrawing the portions of the walls AB, and CD, and clearing the ground to divert the stream waters through N, the double sheet walls FH, and GK, are erected to protect the construction of the section R, to complete the dam. This describes the simple general scheme, but does not describe the many factors that the foundation engineer must consider before he embarks on the job.

If the soil on the river bed is of silt, or soft clay, it would be foolhardy to depend on it as a backfill, either for single, or double wall cofferdams. Besides being of poor frictional value for sliding resistance, it would impose heavy stresses on the sheeting, and further, would increase the hazards of wash outs. It must therefore be dredged out and replaced inside the cofferdam by a fill of high frictional value and heavy density.

The height of the cofferdam will depend upon the depth from the rock surface to maximum expected flood height, making additional allowance for increase of height due to the restriction of the channel. The

backfill most suitable for weighting and sealing the cofferdam is a material of heavy density and high internal friction qualities; a coarse sand or quarry waste being most suitable.

Where rivers are subject to sudden and high floods, such as those of India, to protect construction works as much as possible, diversion channels may be necessary. Failing these it may be an advantage to protect the upstream corner of a cofferdam from violent scour by running an arm of sheeting upstream from the threatened corner, as a continuation of the side sheeting, to streamline the flood waters past the corner, and to prevent dangerous eddies.

A very important point nowadays in cofferdam design is the availability of supply of the steel sheeting. The diverse types of section usually call for special treatment in design, and therefore the latter must be based on what is procurable. It is not so much dependent on the strength of the cross section for bending, as the degree of watertightness, and the tension strength of the clutches. The popular corrugated types of sheet piles, the Dorman Long, Krupp; the B.S.P. Larssen; and the Appleby-Frodingham sections, have the advantages of stiffness and general utility, but call for the use of stout walings and bracings. These types are all of single clutch jaws. The modern practice for large cofferdams in deep water tends towards the circular form to avoid the necessity for walings. The best type of sheeting for this purpose is the straight web with double clutch jaws, such as the Lackawanna, Belval and Senelle types (Fig. 4).

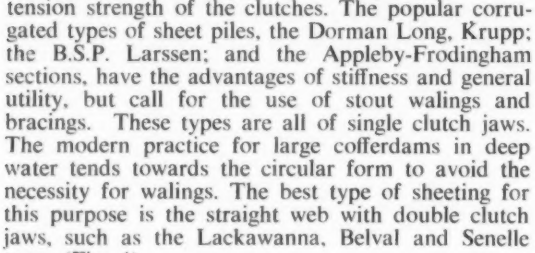



*Fig. 4. Straight web and corrugated web sections*

If the form of the cofferdam is a series of rectangular cells, which is usual for the relatively small works carried out in Britain, then the deep corrugated sections with walings and bracings could not be bettered. Where, however, modern dam constructions have required the use of high cofferdams, either due to the depth of water in which they were sited, or due to the depth of the rock layer below the river bed, various forms of self stable cofferdams have been evolved. These various designs are all variations of circular forms and are dependent upon the clutch strength of the sheeting in tension.

The tension stress upon the circular sheeting due to the backfill only is $T = Pr$ where r is the radius of the circle, and P is the intensity of pressure per unit area. Thus the greater the radius, the greater is the tension in the sheeting for equal intensities of pressure. Now the angles connecting sheets, where a short arc of a circle joins another and a transverse bulkhead, are usually less strong than the clutches. This then is the weakest link, and limits the design unless purpose made connections have been manufactured. The amount of the difference in strength varies in the different types, some being about three times weaker at the angle connection than at the clutch. It will therefore be appreciated that for very high cofferdams containing backfill of low internal friction quality the circular arcs should be reduced in radius to obtain uniformity of strength. To achieve this the different forms of Fig. 5 have been used successfully.

*Fig. 5. Self-stable cofferdam forms*

The outer arcs of sheeting are usually higher than the remainder, and the backfill is highest near the outer wall. Generally, the following points are worthy of note and careful attention. To ensure a minimum of seepage through the great length of joints the preliminary expense of plugging the clutches on the outer face with bitumen cord is advised. Though this entails expense of diver's work, it proves economical in the long run. The old fashioned method of dousing the waters at the outer face with ashes, bran, cement and slag crushings, is not sufficiently effective on the long lengths of sheeting joints to be sealed, particularly where the currents are strong, and the water level fluctuates. The sheeting of the inner wall of the cofferdam should be pierced by holes, here and there, for drainage purposes, and to ensure the relief of hydraulic pressure in the backfill. The ends of the cofferdam should terminate in circular form as shown at Fig. 5 (b) and not in a straight bulkhead unless provision has been made to strengthen it by walings and bracings. The form (d) is more easily driven than (c) but both may be used for deep water. The Kentucky (Tennessee) cofferdam was constructed to the form (c) and was no less than 75 feet high with a base width (overall) of 100 feet. The form (d) is also the more readily adjusted for variations in the depth of water as the width and the height of the wall can be altered without change of the general design. The outer wall of (d) is carried to full height, but the inner wall is much shorter, whereas the intermediate wall of short sheet piles forms the inner face of a parapet just sufficiently wide to withstand the lesser hydraulic pressures of the upper layers.

The width of a cofferdam is based upon the following condition of equilibrium.

$$nP = \mu W$$

where P = total hydraulic pressure on outer face, per unit length.

n = factor of safety, usually 2.

W = effective weight of backfill only, per unit length.

$\mu$ = tan $\phi$ = co-efficient of friction of backfill on the rock sub-foundation. This averages about 0.5 for sandy fill.

Having obtained the weight of the backfill required, and determined the form of the cofferdam section, the fixing of the dimensions is straightforward arithmetic. No allowance is made for the biting of the sheeting

into the rock surface, or even for irregularities of the rock surface.

The snags of the actual driving are many, and to avoid delay in progress, the following procedure represents good practice methods. Guide walings and bracings are first erected either on shore or on site; in straight runs, panels of eight or so sheets are erected, clutched, and driven in two stages, using a long pile driver and a shorter one. In curved sheeting walls driving should be carried out in steps, working around the wall completely several times, reversing the travel each time the origin is reached.

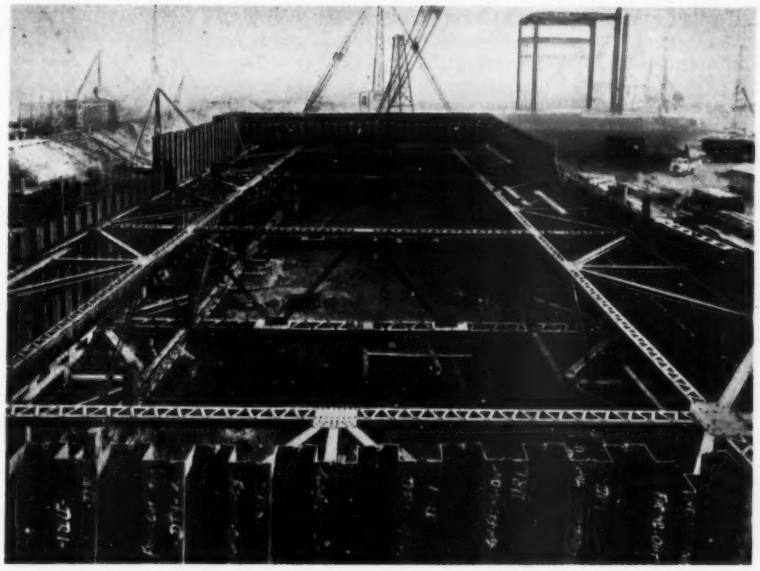


*Fig. 6. The use of horizontal steel trusses and bracings as side supports*

Although most pile sections allow for a clutch deviation of 8 to 10 degrees between successive sheets, some engineers prefer to have specially curved sheets to the required radius to avoid excessive driving resistance and possible straining of the clutches. For pronounced curvatures the whole of the sheeting should be erected in position before commencing driving. In deep water American engineers have found that time and expense have been saved by erecting a complete cofferdam cell on shore, and then floating it out to the site, where temporary timber piles had been driven, to guide the cell into position. The driving is then carried out from floating pile driving plant. When obstructions, such as buried tree trunks, are encountered, instead of punishing the pile by trying to force it ahead, it should be left and the next pile driven. This may release the obstruction to the first.

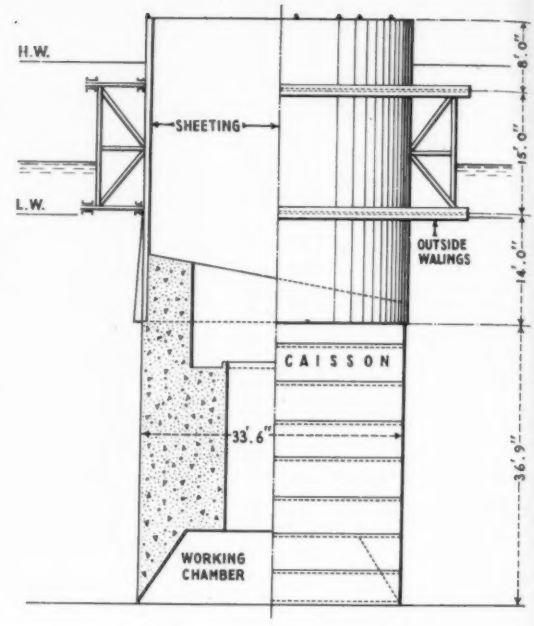
Just before the war the contractors (Engineers—Merz & McLellan and Sir Alexander Gibb & Partners; Contractors—Holloway Brothers and Company) of the Littlebrook Power Station introduced a new and bold design for large cofferdam construction entirely in steel. The work was undertaken for pump house, screen, and penstocks, for the new power station situated in marshy ground on the banks of the Thames, where the ground level was eight feet below high water level, and fourteen feet below the top of the protection bank. The borings of the ground on site revealed a water bearing chalk layer 54 feet below ground surface. Overlying the chalk there was a 20 feet thick bed of ballast, and on this, beds of sand, peat, and silt to ground level. When piercing the borehole into the chalk it was noted that the fluctuations of the tides caused the water to rise and fall responsively in the drill casing, a twelve feet rise of tide causing an eight feet rise of water in the tube. This provided a new problem which called for precautions not only to prevent a blow inside the projected cofferdam but also to prevent the flooding of the ground area outside the cofferdam at high water. Thus the top of the cofferdam sheeting was fixed at eight feet above ground level and the underside of the foundation mattress at 40 feet below ground level.

*Fig. 7. A bold design for cofferdam construction*

It was decided to drive Dorman Long K III section piles 60 feet long in a single wall, down to the chalk. The area covered by the foundations was 150 × 76 feet. To facilitate the operations inside the cofferdam it was decided to dispense with the usual large quantities of timber strutting and walings, and use horizontal steel trusses and bracings as side supports (see Figs. 6 and 7). This left clear spaces about 40 feet square for working. There were three frames of which the upper two are shown in the illustration. These two frames were erected on the ground in their position in plan, being strutted and braced vertically to form a rigid box frame. The K III sheeting was then driven around the periphery; four groups of timber piles seen in the forefront of Fig. 6, were also driven to provide supports for the lowering gear from which the frames were suspended. As the excavation proceeded, the frames were lowered foot by foot till eventually they reached the designed vertical position. Then at each pile section wedges were inserted between them and the frames, and driven home effectively. The third and lowest frame in sections was then lowered inside the cofferdam and connected up on the top of the excavated ground: it was then suspended from the positioned upper frames by screwed bolts which controlled its vertical position as the excavation progressed. The fear of a blow was always present and to safeguard the works from a premature inrush of water at each downward advance of the frame, wedges were inserted, and driven hard home. Ample pumping plant was installed to deal with any eventuality, but fortunately, it was only called upon to deal with the heavy continuous seepage. The care with which the contractors carried out the work to their designed method of construction, and contingencies, proved the worth of the innovations, as the ten feet thick concrete foundation mattress was laid continuously, without delay by " blows " or the removal of interfering struts, props or walings.

Steel sheet piles are not always driven into soil; their uses are varied. A case in point is where they are used to form an extension cofferdam to a sunken compressed air caisson forming the intake shaft of a power station. The method of construction by Messrs. Holloway Bros. (London) Ltd. was ingenious and gave most satisfactory results. A steel caisson (Fig. 8) 33 ft. 6 in. x 30 ft., filled with concrete formed the lower portion of the inlet shaft to the circulating water tunnel, and was sunk to grade in a tidal river bed. To facilitate the control of the caisson during sinking operations four groups of timber piles were driven into the river bed, in the positions shown in plan, to support the lowering gear, which was connected to brackets at the four corners of the caisson.

The difference of the weight of the caisson at the cutting edge, due to the fluctuation of the tides, between high and low water, amounted to 650 tons which was the amount the lowering gear was designed to take. The caisson also formed the foundation for four 6 ft. diameter concrete piers supporting the deck of the coaling jetty, as well as the heavy timber trash screens boxing off the intake of the river water; the four sides of this screen spanned the spaces between the four circular piers. The concrete walls of the upper part of the caisson were set back from the lower face, as shown in the cross section, forming a ledge around the caisson at 36 ft. 9 in. above the toe. From this ledge to the high water level was 36 ft. Steel sheet piles of Dorman Long K 11 section 37 ft.



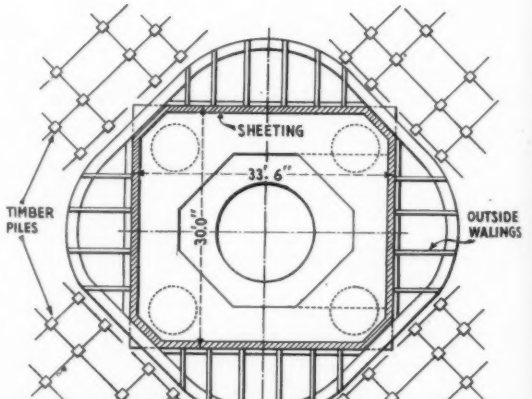




*Fig. 8. Sheet pile cofferdam extension to caisson*

long were welded together in twos and threes to form panels 5 ft. 4½ in. and 7 ft. 10½ in. wide. These were fitted with base plates carrying rubber strips to act as water seals when placed in position on the ledge.

The chamfering of the corners doubled the number of special angle connections, but facilitated the design of the arched waling supports. As the whole space of the inside of the cofferdam was required for constructional work, in place of the usual internal strutting and walings it was decided to support the side sheeting by external frames, to which the sheeting was bolted. These frames were, in effect, bowed parabolic trusses with common tangents at the corners, as shown in plan view. They were placed 15 ft. apart, rigidly braced and connected up to the sheets.

These few examples by no means exhaust the uses to which sheet and bearing piles are applied, but they do serve to show the versatility of their constructional aid.

# Classic Swiss Schemes

By HENRY NIESZ. The characteristics of six outstanding hydro-electric plants in Switzerland, and their influence on the country's economy, are examined.

*L'auteur étudie les caractéristiques des six stations hydro-électriques les plus intéressantes de Suisse et leur influence sur l' économie du pays. Bien que le coût de l'énergie produite par les stations d'accumulation, dont la production est constamment réglée par les besoins du moment, soit plus élevé que celui de l'énergie produite par les stations au fil de l'eau, tributaires du débit d'un cours d'eau, la combinaison des deux systémes offre de grands avantages. On trouve en Suisse un exemple classique de systéme hydro-électrique ainsi coordonné.*

*Se hace un estudio de las seis instalaciones hidroeléctricas más interesantes de Suiza y de su influencia en la economía del país. Si bien el costo de la energía producida por estaciones de almacenaje, cuya producción es controlada por las necesidades del país, es más importante que la fuerza generada en estaciones de flujo controlado, las cuales dependen del flujo de la corriente en cuestión en cualquier momento determinado, una combinación de los dos sistemas ofrece grandes ventajas. Suiza ofrece un ejemplo clásico de un tal sistema coordinado para la generación de energía hidroeléctrica.*

THE general economy of Switzerland is dominated by geographic conditions which, it might be supposed, would inevitably reduce the whole Swiss nation to poverty and prevent all rational economic development. The country has only insignificant deposits of minerals and coal, and its subsoil has no deposits of liquid fuel. The activities of its inhabitants should logically be restricted to agriculture, the raising of cattle, and the working of the forests. It is by no means so, however, because from time immemorial the Swiss have taken pains to widen continuously their field of activity well beyond the narrow limits fixed by nature. Guardians of the high passes through the Alps, in the centre of Europe, they have been in contact since the Middle Ages with merchants in neighbouring countries. They have themselves become merchants, and international trading has led them, little by little, to set up their own industries using above all, in mechanical form, the water power which is the only wealth that nature has lavished on Switzerland.

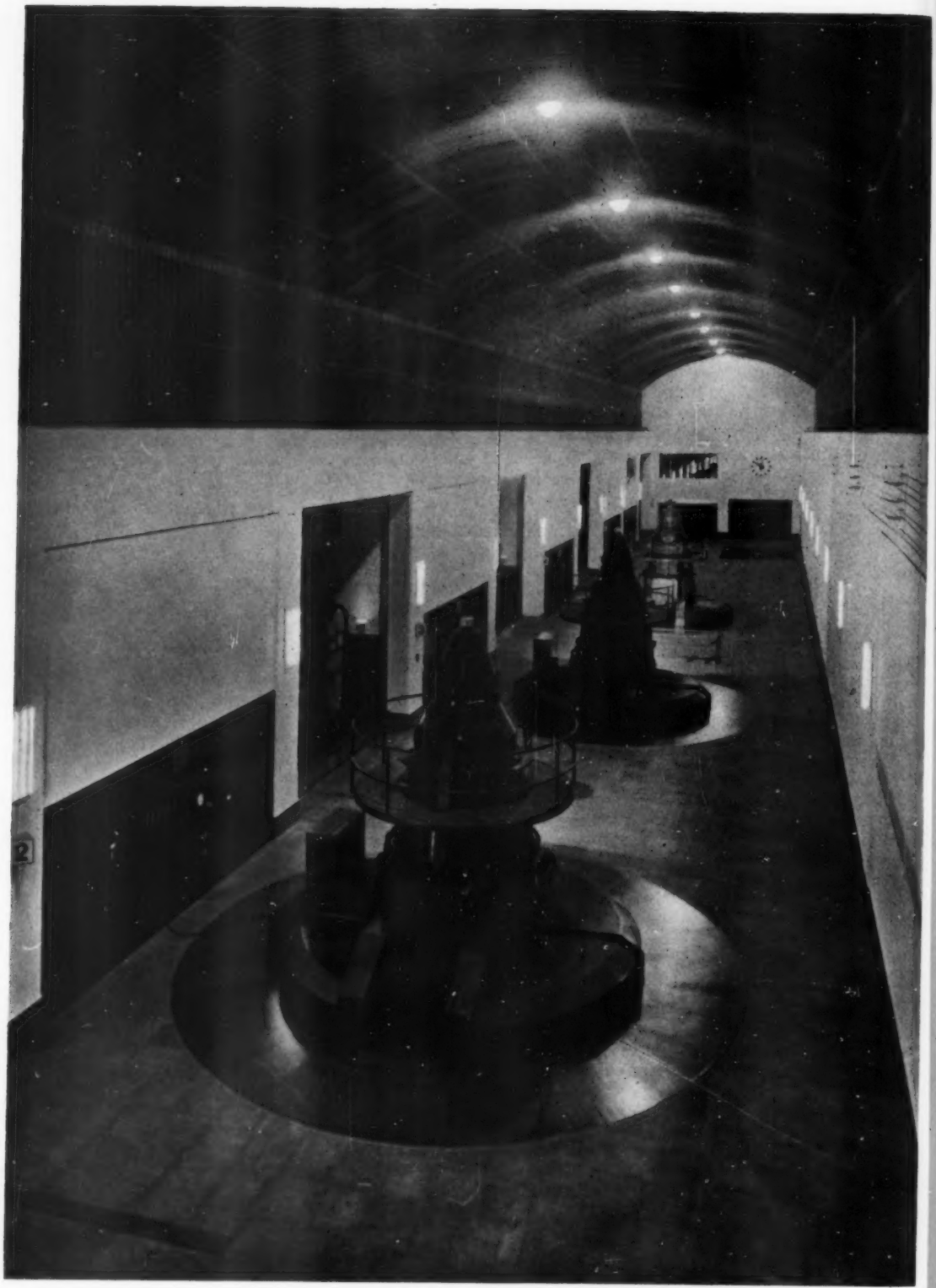
Since the end of last century, the profound economic revolution caused by the practical application of electricity has resulted in a rapid increase in the use of hydraulic power, and Switzerland leads the world today with the highest annual production of 2,220 kWh for each inhabitant.

Like many other countries, Switzerland is now faced with a serious discrepancy between the production and the consumption of energy, because during the war the shortage of solid and liquid fuels gave great impetus to the electrification of industry and of the private home, leading consumers to replace fuels by electricity for numerous purposes. During the same period the building of new hydro-electric stations was held up, and this has led to the restriction of consumption at low-water seasons. Plans for powerful stations with large storage capacity are ready for execution, but unfortunately they have encountered great difficulties of various kinds, particularly when they require the flooding of villages. Fig. 1 shows the rate of increase in the production of electric power in Switzerland.

**The Role of Water Power**

The characteristic feature of Swiss electrical economy is the practically exclusive rôle of the hydraulic production of electric power. It is quite natural that a country in which the supply of fuel depends almost entirely on other countries, but which possesses such abundant resources of hydraulic power as Switzerland, should not use thermal power stations. Nevertheless, a certain number of electricity undertakings and factories have reserve thermal plants for emergency service or occasional peak loads. Their total power is 120,000 kW, while the total installed power of Swiss power stations is about 2.6 million kW; but their production of power is, in proportion, far lower still, because of the exceptional nature of the duty they are called upon to perform, and hardly exceeds 6 million kWh a year, while the total production is 10,000 million kWh a year. Nevertheless, this preponderance of hydraulic generating stations has not prevented Swiss industry from building Diesel engines, turbo-groups, and steam boilers, as well as gas turbines, for use in thermal power stations throughout the world.

As Swiss territory forms part of the Alps, its watercourses are mainly fed by the melting of snow and glaciers. In their upper reaches, they are torrents of extremely irregular flow—abundant in the extreme in summer, but insignificant in winter. At the outlets of the alpine valleys, the flow of the rivers is partly regulated by fairly large natural lakes. This fact renders very economical the running of the large " stream-operated " power stations set up on the great



*Innertkirchen Power Station, which is excavated in rock*

watercourses. Nevertheless, the variations of flow are still great, and the ratio between the maximum and minimum flows utilised is, in the case of the Rhine at Bale for example, about 3 to 1.

**Great Economic Advantages**

As the demand for power is not smaller in winter than in summer, but quite the reverse, it has been

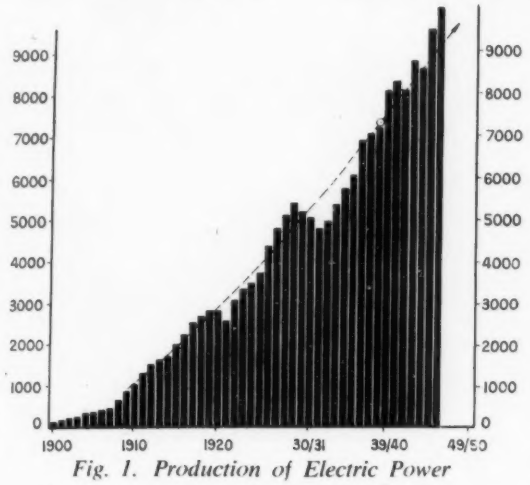



*Fig. 1. Production of Electric Power*

necessary to supplement the output of the stations known as " stream-operated," which is dependent on the flow at a given time of the stream in question and hence is variable, by the output of stations provided with annual storage basins, the output of which is controlled at all times by actual needs. The cost of power produced by storage stations is higher than that of the power produced by stream-controlled stations, but the combination of the two types of stations offers great economic advantages. It has of course been necessary to provide close interconnection between these two types of station by very high tension lines. Fig. 2 shows the respective parts now played by power produced by stream-controlled stations and that produced by annual storage stations. The second type represents 1,000 million kWh a year,

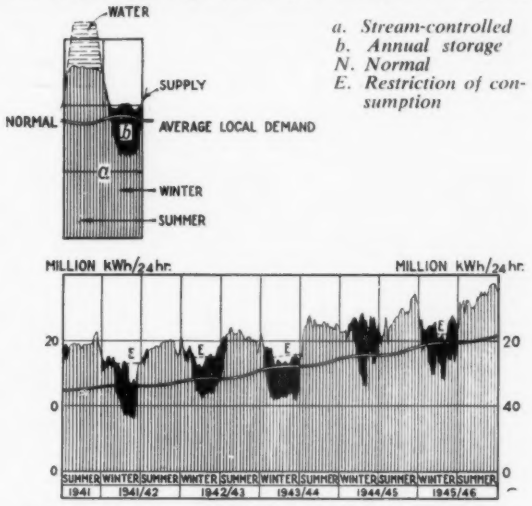


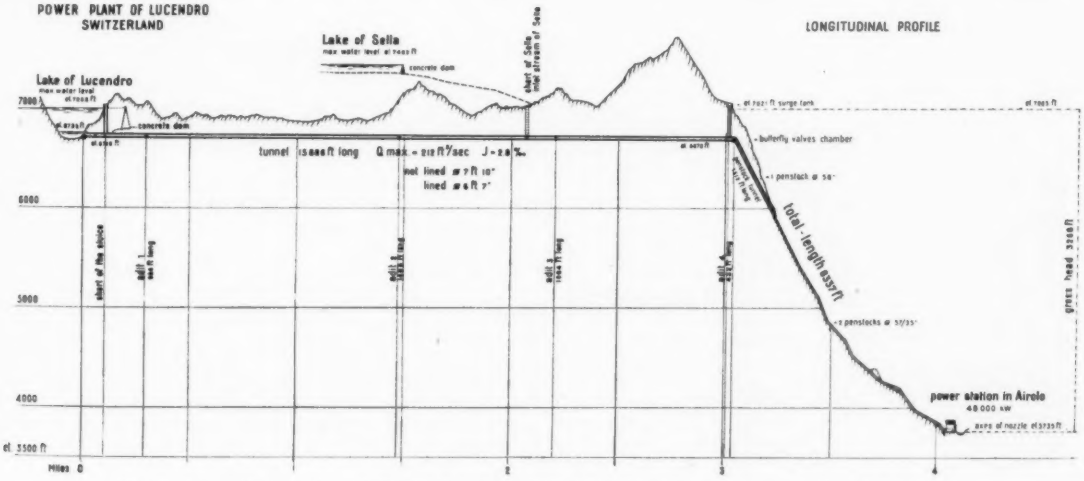

*Fig. 2. Stream-controlled and storage generation*

out of a total production of 10,000 million kWh.

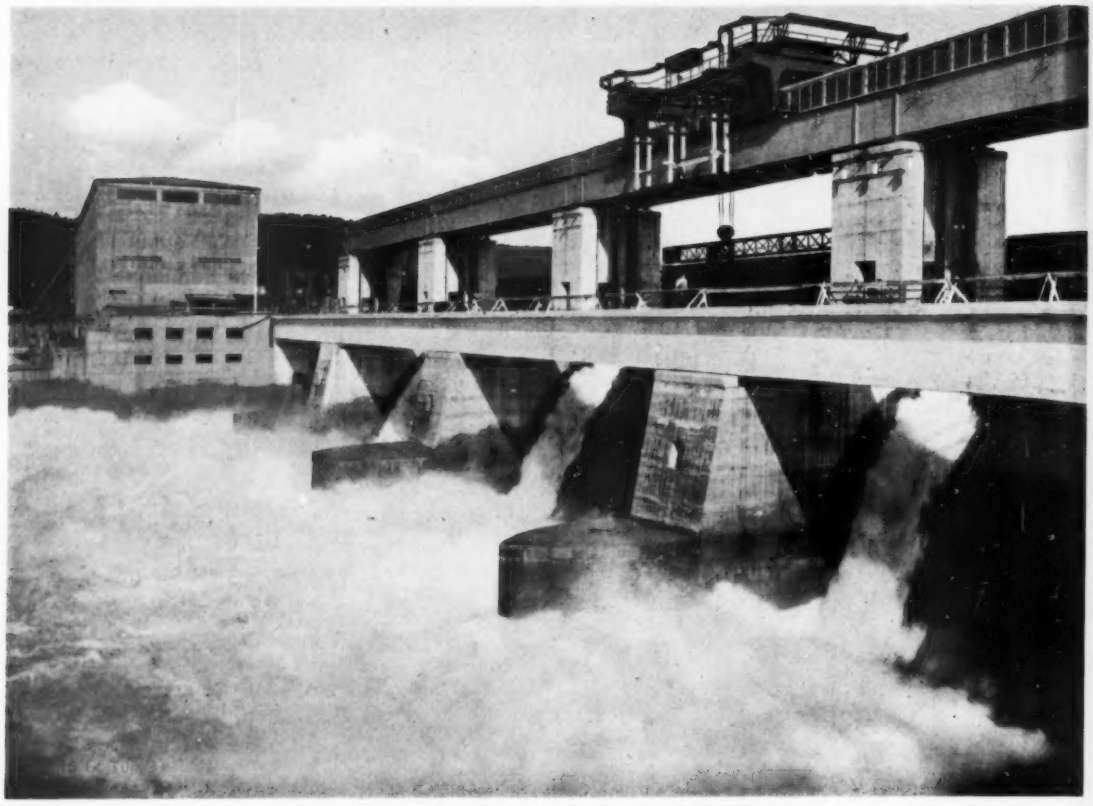
**Stream-Operated Stations**

The characteristics and views of the six most interesting plants in Switerland will be examined in some detail because together they provide a classic example of a co-ordinated hydro-electric system, which has had a fundamental influence on the nation's economy. Three of the stations are of the " stream-controlled " type, including Ryburg-Schwoerstadt on the Rhine, Verbois on the Rhône, and Rupperswil on the Aar; the other three, Dixence, Oberhasli, and Lucendro, are of the annual storage type.

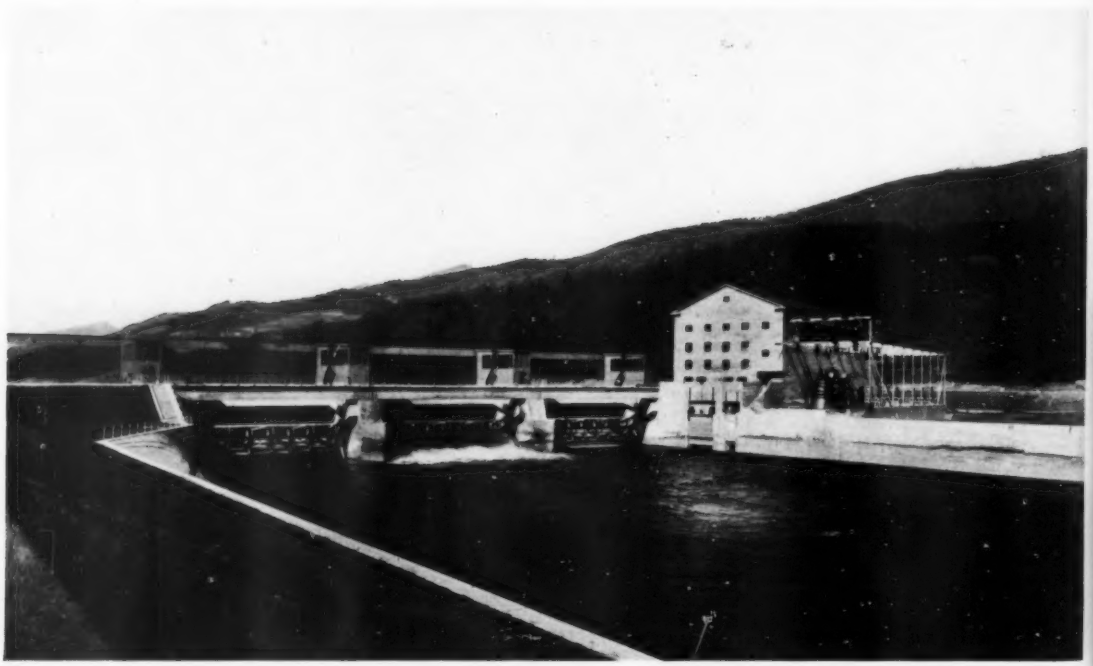
The installation at Ryburg-Schwoerstadt, near Bale, is the most powerful of all the power stations on the Rhine upstream of that town. The station was planned by Motor-Columbus S.A. d'Entreprises Electriques, of Baden (Switzerland), who also directed



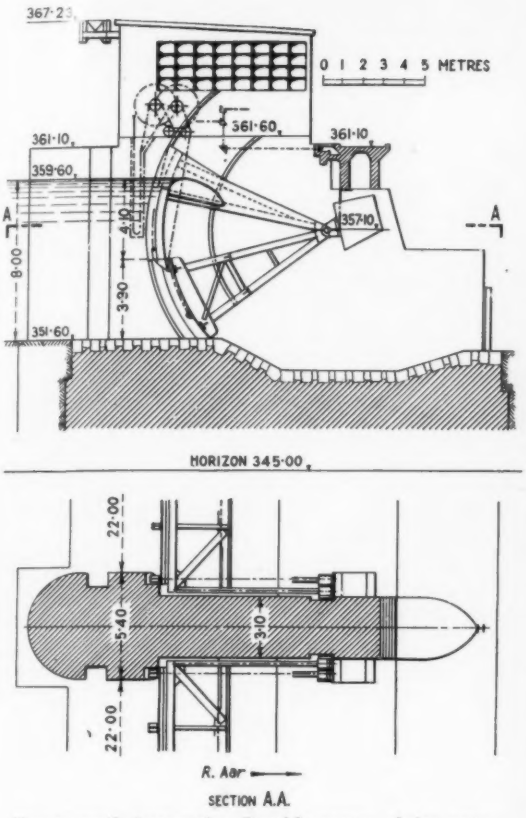

*Water from the glacier of Lucendro, instead of flowing naturally to the North Sea, is diverted towards the Adriatic*



*Ryburg-Schwoerstadt — a "stream-controlled" station*

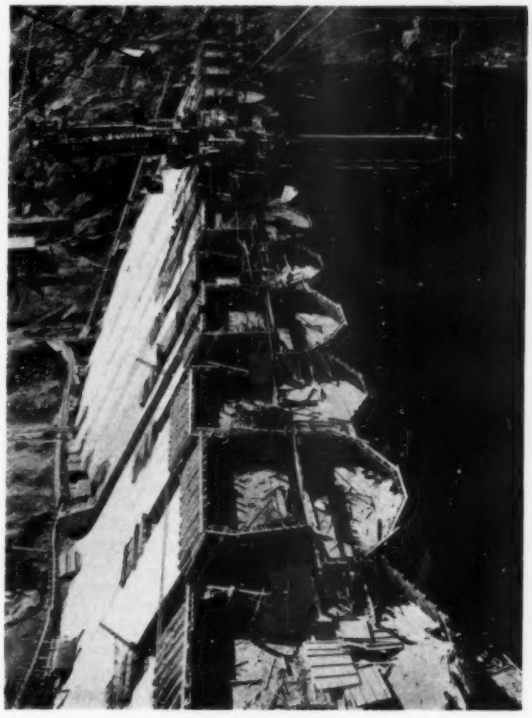


*Rupperswil-Auenstein, on the River Aar, looking up stream*

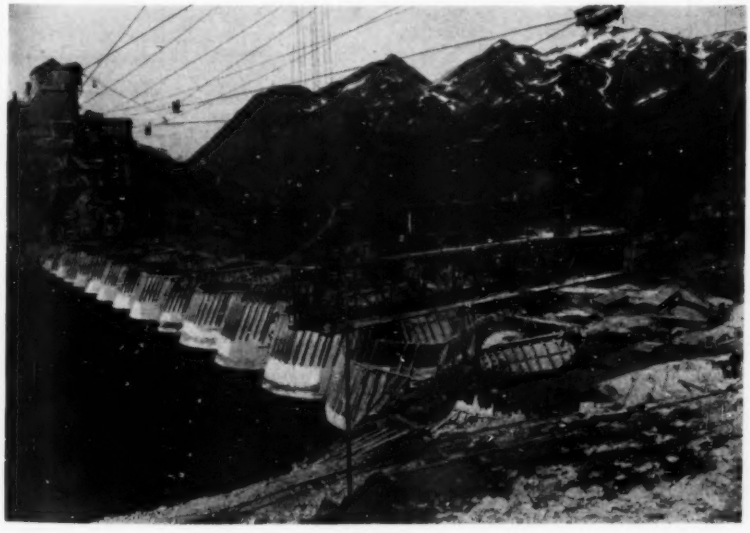



*Rupperswil-Auenstein: Double sector sluice-gate*

the work. This is a barrage power station providing a drop of 39 feet. The four vertical axis Kaplan turbines turn at 75 r.p.m., and can each absorb 16,600 cubic feet a second. The maximum power of a group is 28,500 kW with a drop of 37 ft. 9 in. In the tests the output of the turbine reached 92.7 per cent. It is interesting to note that this station was the first in the world to use high power Kaplan turbines. Other innovations, used for the first time in this plant, were the replacement of the inlet gates of the turbine by transportable dams, the use of mobile blades in the distributor of the turbines in conjunction with the variable pitch blades of the Kaplan wheel, in order to effect rapid cutting of the passage of water, and the use of these latter blades for braking. The annual production of the Ryburg-Schwoerstadt power station has reached 812 million kWh during the last ten years.

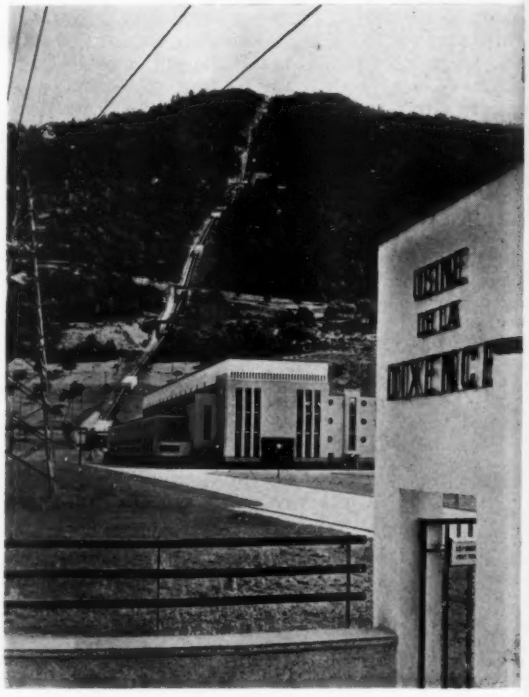


*The Lucendro Dam: The gravity-cellular construction in progress*



At the beginning of the war, another great stream-controlled power station was built in Switzerland, on the Rhône, at Verbois, some miles downstream of Geneva, by the electricity authority of that town. The working out of the scheme and the direction of the work were undertaken by the Société Générale pour l'Industrie Electrique, of Geneva, in collaboration with Motor-Columbus for the planning of the barrage. This barrage power station uses a drop of 69 feet. At the present time three vertical axis groups, each of 22,000 kW, are installed; a turbine room is ready to receive a fourth group later on. Each group

*Above: Annual Storage Systems at Oberhasli showing both dams and the Finsteraarhorn in distance*
*Right: Pipeline to Dixence Station*



comprises a Kaplan turbine rotating at 136 r.p.m., absorbing a flow of 4,500 cubic feet a second, and a three-phase 50 cycles per second alternator, of 27,500 kVA, 18 kV. The power produced is transmitted to the Geneva network at the voltage of the alternators, or is raised to 125 or 150 kV for the Swiss or French networks.

The Rupperswil-Auenstein stream-controlled power station on the Aar, downstream of the small town of Aarau, built by the Swiss Federal Railways and the S.A. des Forces Motrices du Nord-Est de la Suisse, was put into operation in 1945. It is equipped with two Kaplan turbines of 17,000 kW each, utilising a flow of 600 cubic feet a second. One of them drives a three-phase alternator of 22,000 kVA, 50 cycles per second, 5.7 kV, supplying power for general consumption, while the other drives a single phase alternator of 25,000 kVA, at $16\frac{2}{3}$ cycles per second, 11 kV, transmitting to the Federal Railways network. The annual production of this power station is about 210 million kWh.

The barrage connected with the Rupperswil power station contains an interesting innovation: each of its three sluices is formed by a double sector-gate, composed of a lower sector-gate of the conventional type and an upper sector-gate extended downstream by an incurved sheet metal overfall. The two gates

*Ryburg-Schwoerstadt Station on the Rhine. Left: Reinforced concrete Pylons for high tension lines*

are so disposed that the upper gate can slide in front of the lower gate. This novel type of gate, for dam heights which are not too great, has great advantages over the types previously used, both from the technical and economic points of view. The double sector-gate does not require a footbridge for the winches, the mechanism being installed on the columns of the barrage; the supports of the gates are simple and the gates require less powerful raising mechanism. The appearance of the barrage is also more æsthetic.

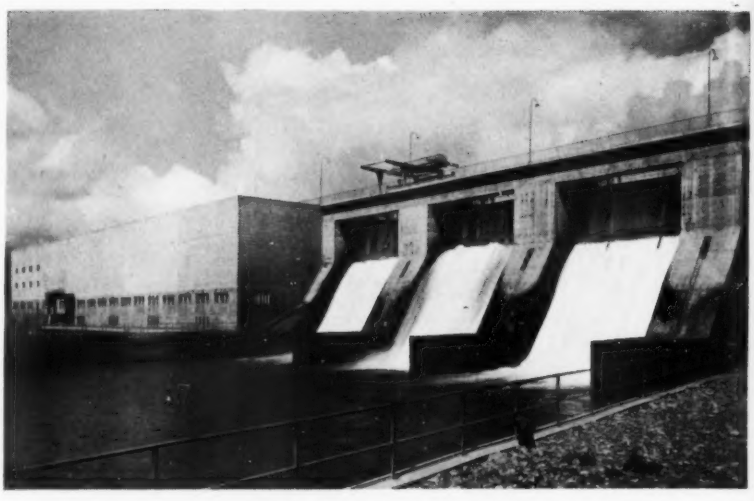
In these three stream-controlled installations, the proportion of power for the winter period to that of the summer period is about 45 per cent. to 55 per cent.

The Dixence storage power station, built under Government supervision by the Société l'Energie de l'Ouest-Suisse, of Lausanne, has the highest drop used in the world. It is situated in the canton of Valais, near Sion, and uses the waters of a tributary of the left bank of the Rhône, which are dammed at a height of 7,351 feet by a barrage and return to the Rhône at the height of 1,611 feet; when the lake is full the static drop thus attains 5,470 feet. The barrage, which has a maximum height of 285 feet and a developed length of 1,504 feet, belongs to the gravity-cellular type. It has 31 buttresses of non-reinforced concrete, coupled in pairs in order to increase transverse rigidity.

From the water tower situated seven and a half miles from the barrage the water is brought to the power station through two extra-mild steel pipes, which are strengthened by iron bands lower down because of the great pressure of water. The speed of the jet impinging on the turbines is 590 feet a second. The power station comprises five main groups of a maximum power of 37,000 kW, each constituted by two single-injector Pelton turbines using 44 cubic feet of water a second and disposed one on either side of a three-phase alternator, 37,500 kVA, 13 kV. The Dixence power station can transmit its power over four 130 kV lines to all the large centres of French-speaking Switzerland and, through the medium of the Galmiz transformer station, to the large networks of German-speaking Switzerland which operate with a voltage of 150 kV.

The Oberhasli power stations were designed and built under the direction of Dr. Kaech, of Berne. They make use of the Upper Aar, dammed in the reservoir lake of Grimsel, which is closed by two large barrages: the combined weight-vault barrage of Spitallam and the rectilinear weight barrage of Seeuferegg. The former is the highest of all Swiss barrages. Its height is 374 feet and the volume of concrete used in its construction was 12 million cubic feet. Incidentally, the great American Boulder Dam was built some years later on similar principles. The lake thus formed has a useful capacity of 3,500 million cubic feet and bathes the end of the great glacier of the Aar. The waters flow through a tunnel into the lake of Gelmer, the useful capacity of which is 460 million cubic feet, and thence descend through an inclined shaft under pressure to the Handeck power station.

A second fall was provided in 1940. From Handeck a supply tunnel some six and a quarter miles in length leads to a vast underground water tower, which comprises in particular a vertical shaft 200 feet in height and of circular cross-section, the diameter being 27 feet 7 inches. The water tower is the origin of the inclined and armoured shaft through which the water falls to the power station. This shaft has a length of 1,980 yards, and covers a difference in level of 2,215 feet. Its cross-section, the diameter of which falls from 8 feet 6 inches to 7 feet 10 inches, permits a maximum flow of 1,270 cubic feet per second. Like the supply tunnel, the water tower and the shaft under pressure, the Innertkirchen power station is likewise excavated from rock. It is a cavern the dimensions of which are: length 330 feet, width 64 feet, height 85 feet. It accommodates at present three groups of machines; two supplementary groups, identical with the first three, will be installed in a few years' time, in emplacements already provided. The double spherical gates, which control the access of the water to the turbines, are installed in a separate excavation between the distribution conduit and the power station. Each group comprises a vertical axis, double injection Pelton turbine supplying 41,500 kW with a net drop of 2,133 feet at a flow of 265 cubic feet per second. The turbine drives, at a speed of 428 r.p.m., a three-phase alternator of 47,500 kVA, 13.5 kV, and an exciter with pilot exciter mounted at shaft-end.



*The Verbois Station, near Geneva*

The transformers are housed in the same cavern; they raise the voltage to 160 kV. The power is transmitted by cables to the open-air coupling station. The Oberhasli stations can concentrate their production on 3,000 hours a year; only half of the output represents power produced from the storage system. The heightening of the two barrages at Grimsel is at present being studied, as well as the provision of new storage lakes fed by other tributaries, so as to increase the proportion of power by this means.

The hydro-electric installation at Lucendro, on the other hand, is purely a winter storage station, the output of which is concentrated on a theoretical working period of 1,700 hours a year. It is located in the St. Gotthard massif, and has an interesting geographical peculiarity; the water of the Upper Reuss, issuing from the glacier of Lucendro, is dammed by a large barrage and, instead of flowing normally to the Rhine and the North Sea, is diverted towards the Tessin, that is to say towards the Po and the Adriatic. This change of the natural conditions of flow enables a higher output of power to be obtained, because the fall is greater and the slope steeper on the southern slope of the Alps than on the northern slope. This additional water also contributes towards improving the flow of the Tessin, which hitherto was particularly sluggish in winter.

Like the barrage at Dixence, the one at Lucendro is of the gravity-cellular type (Noetzli system). It enables the level of the small natural lake of Lucendro to be raised and 883,000,000 cubic feet of water to be stored, the water intake being situated 66 feet below the original level of the lake. Although the height of the barrage is 225 feet, the volume of concrete is relatively small—about 5,500,000 cubic feet. The upstream wings of the columns of the barrage touch one another and constitute a mask the tightness of which is ensured by a special jointing. Downstream, the free space between the buttresses is closed by insulating plates, in order that the temperature may remain as constant as possible inside the cavities. Another 318,000,000 cubic feet of water are dammed in a neighbouring lake — the lake of Sella — the level of which is raised by a gravity barrage 105 feet high. The crown of the Lucendro barrage is at an altitude of 7,006 feet and the Sella barrage at an altitude of 7,045 feet, is at Airolo, near the southern gate of the St. Gotthard tunnel, houses two groups of 30,000 kVA each, working with a gross fall of 3,270 feet; each turbine, of the single-injector Pelton type, is built for a maximum flow of 117 cubic feet a second. In normal hydrological conditions, the output is 78 million kWh, entirely concentrated in the winter. To this figure must be added the increased production of the two previously existing downstream stations, *i.e.*, 37 million kWh, due to the additional flow from Lucendro.

The power station is connected to the St. Gotthard high tension line, which transmits the power produced by the Tessin stations to the industrial regions of Northern Switzerland. This line operates at 150 kV, but its supports are built to permit a changeover to 380 kV. The line attains the altitude of 7,200 feet and crosses two valleys with spans of 1,100 and 1,300 yards. The Airolo power station, furthermore, has just been connected to the powerful stations of the Upper Rhône valley by a 150 kV line, the maximum altitude of which, at the Nufenen pass, is 8,160 feet. Over part of the distance it is mounted on pylons of a new type, consisting of steel tubes filled with concrete, which enable considerable savings in metal to be made and give the supports a slender and æsthetic appearance—so safeguarding the wild beauty of this high Alpine valley.

# Plant for peak load operation

By A. R. Cooper, M.I.E.E., M.Inst.F., Divisional Controller (Merseyside and North Wales Division) of the B.E.A. Relative merits of steam and hydro-electric plants are discussed ; in the development of a combined system, the author shows that the higher the percentage of hydro capacity the greater the caution must be in assessing "firm" kilowatts.

*En Grande Bretagne où le potentiel hydro-électrique est relativement faible, l'usage est d'en réserver l'emploi aux périodes de pointe sur le réseau national, laissant aux génératrices à vapeur le soin d'assurer le débit de base et les charges secondaires. L'auteur note qu'une augmentation de la puissance hydro-électrique, exprimée en pourcentage de la puissance totale disponible, entraine nécessairement un accroissement du matériel mis en jeu par Kilowatt de capacité lorsqu'il s'agit d'évaluer le débit minimum garanti; de même, plus critiques sont les effets des périodes de sécheresse relative sur la sécurité du système.*

*En Gran Bretaña donde la fuerza hidraulica disponible es relativamente escasa es costumbre de utilizarla cuando se trata de " peak loads "—ó sea la demanda recargada—del sistema nacional, dejando para los usos secundarios la provisión de fuerza motivada por vapor. El autor observa que el mayor que sea el poder de generadores hidraulicos indicado por el tanto por ciento del total, el mayor tambien debe ser el número de las unidades asociadas con cada kilowatt de la capacidad total de la instalación al fijar el número " firmes," y el más peligrosos serán los efectos de periodos de sequía relativamente grave sobre la seguridad del sistema.*

IN Great Britain where the water power available for the generation of electricity is comparatively small, it is the practice to utilize this source for dealing with the peak loads on the national grid system, leaving the secondary and base loads to be met by steam plant.

When schemes are being prepared for the development of combined steam and hydro-electric systems, consideration has to be given to the individual characteristics of each type of prime mover. The capital cost of hydro-plant may be two or three times that of steam driven plant of the same capacity; but the operation and maintenance costs of hydro plant are very low, and almost negligible compared with those of steam plant.

The availability of hydro plant is of the order of 95 per cent. and higher, while that of steam plant is rarely in excess of 80 per cent. In regard to flexibility of operation, steam plant is probably more suitable for fine limit governing, but hydro plant is better able to deal with sudden load changes of large magnitude.

The maximum rate of change recorded on steam driven sets in this country is probably of the order of 5 MW a minute, but whenever possible it is restricted to about one quarter of this figure; with hydro-electric plant, however, the rate is frequently as high as 15 MW a minute In starting up from the completely shut down or cold condition the hydro set can be on full load within three to fifteen minutes, depending on the pipe line layout, while steam plant of any appreciable size will usually require a period of some two to three hours. The steam station usually requires at least twice as many men per kW as a hydro station. The extra work involved in coaling, ashing and maintaining steam plant is too obvious to need emphasis.

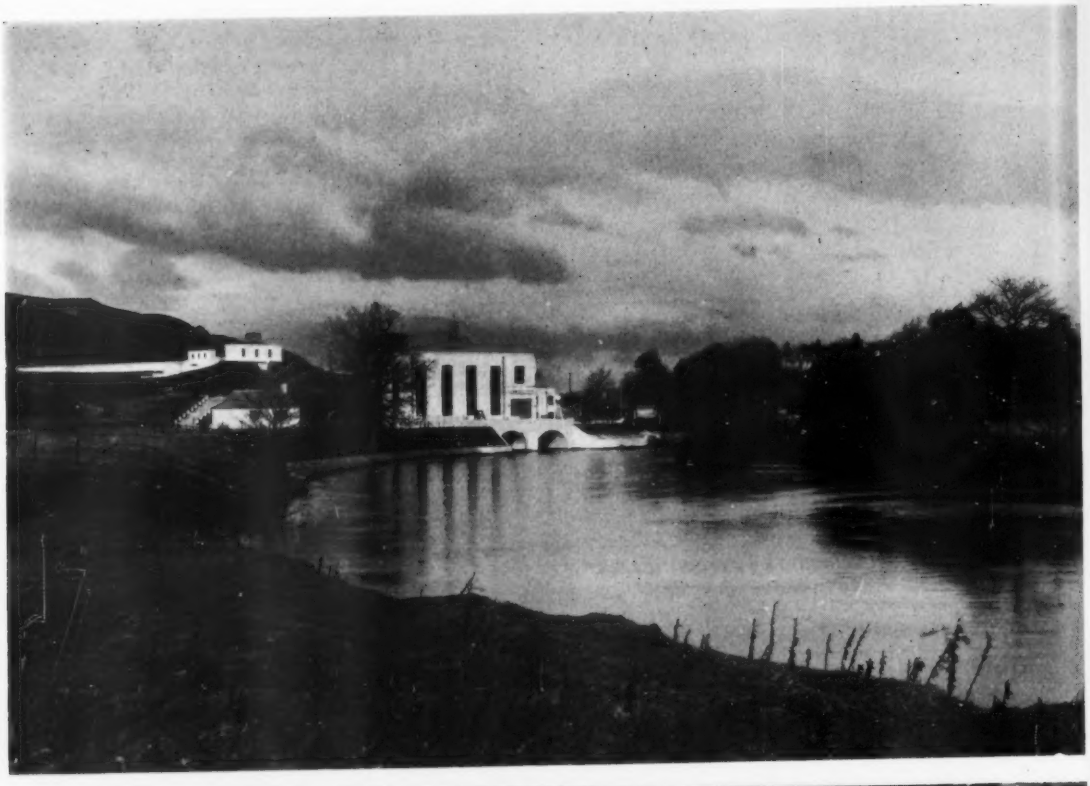
The fundamental operating factor in favour of the steam station is that so long as the plant is available it can be run at full capacity continuously by maintaining supplies of fuel, while the total output of the hydro station varies with the total rainfall. With a stable rainfall and appropriate storage capacity the full output capacity of the plant can usually be regarded as available throughout the daily heavy load periods of the year, but the unpredictability of droughts or long periods of low rainfall always make the output capacity of hydro plants less reliable than that of steam plants.

By reducing the hours of operation of hydro plant it is possible to obtain from the same total water supply a greater kW output, and by so doing to avoid or to reduce the amount of generation by inefficient and costly steam plant which would otherwise be used for peak load working.

**Assessment of " Firm " Kilowatts**

In planning the development of combined steam and hydro-electric systems, it becomes necessary to assess the output capacity in kWs. which can be relied upon from the hydro-electric resources, in order that an appropriate amount of steam plant can be included in the development programme. This assessment of what is known as " firm " hydro kilowatts becomes a matter of judgment rather than of mathematical calculation. The cautious planner will assess the hydro kilowatts on the basis of the driest period ever recorded, whilst the economic planner will veer towards the adoption of average conditions and will regard drought or low rainfall periods as operational hazards in the same way that breakdowns of steam plant are operational hazards.

In this connection it should be noted that the greater the amount of hydro plant expressed as a percentage of the total plant on the system, the greater must be the units associated with each kilowatt of plant capacity when assessing the " firm " kilowatts, and



*Earlstoun Power Station at Galloway; and below---an aerial view of the Tongland Power Station*

the more critical will be the effects of comparative drought periods on the security of the system. In other words, the higher the percentage of hydro capacity the greater the caution which must be exercised in assessing the " firm " kilowatts.

When a decision is reached on the " firm " kilowatts to be allocated to hydro plant, the total plant capacities are set off against an estimated load duration curve for the period under review which might be one year, one month, or even a shorter period (See Fig. 1).

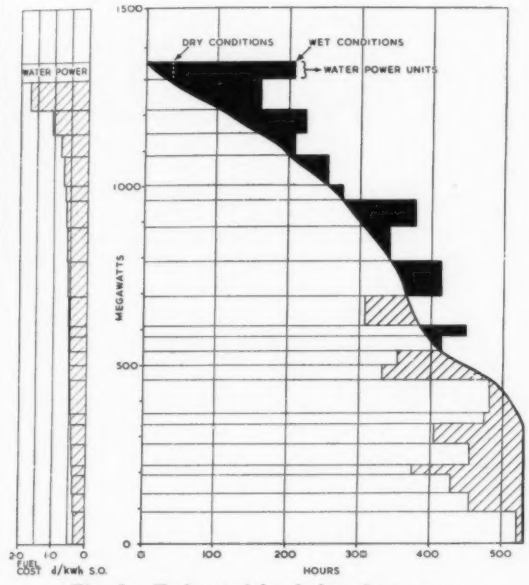



*Fig. 1. Estimated load duration curve*

The ideal performance would be obtained if each set generated the number of units enclosed between the parallel lines connecting its own ordinate to the boundary of the curve. This theoretical performance never occurs in practice, however, due to such factors as low availability of high merit plant and lack of flexibility of second line plant. This can be seen from the curve showing some of the results which have occurred in practice.

**" Off peak " Load Generation**

It will be seen that the hydro plant in this case has generated far more units than were theoretically appropriate and it might be argued that more kilowatt capacity could economically have been associated with the total water supply. It should be remembered however, that many of the units were generated at times of " off peak " in order to avoid spilling water, and also that some margin of output had to be retained as an insurance against drought conditions.

In the day-to-day operation of the system the hydro plant is usually started and raised to its full output during the period 08.00—09.00 hours daily. This high speed injection of hydro kilowatts assists the steam plant in dealing with the rapid rise of load. In the same way, the full range of the hydro plant can be used for dealing with the lunch-time drop in load and the afternoon pick up as shown in Fig. 2. It would normally be shut down after the afternoon peak load in order to conserve water for the following

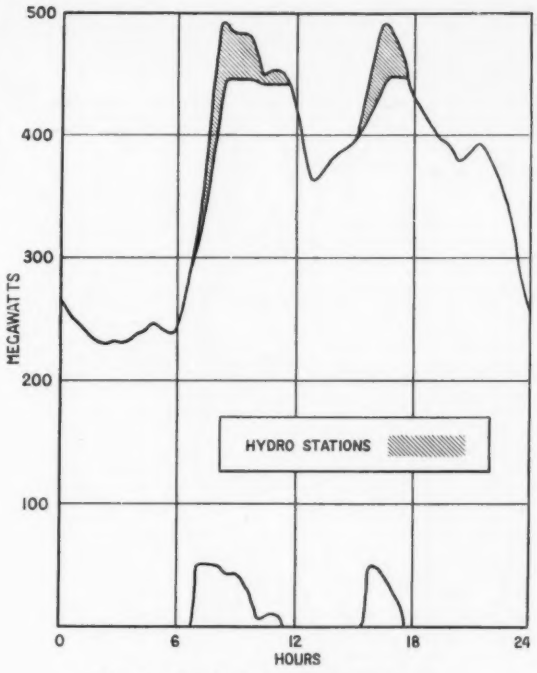
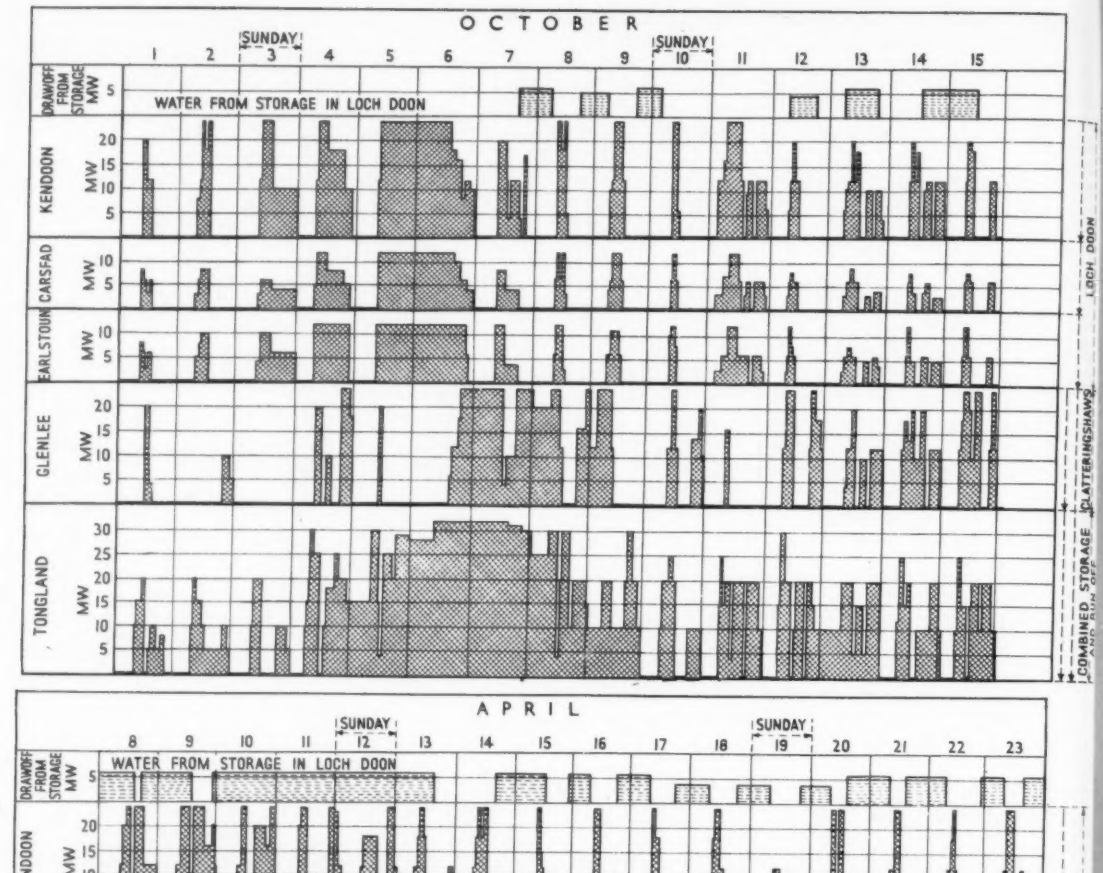


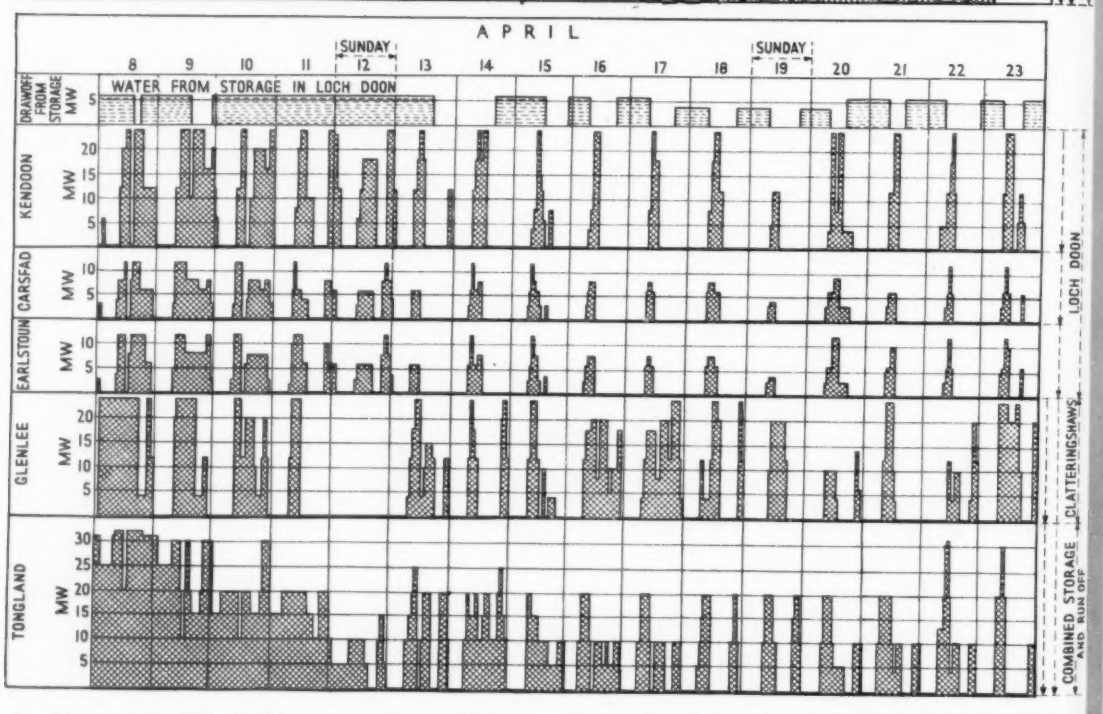

*Fig. 2. Typical daily output curve*

day. In providing the typical daily output (shown in Fig. 2), it is comparatively simple to ensure that the hydro plant at a single station with a straight connection to its own reservoir will be able to give its full output at the appropriate times. But in cases where the same water is used successively in a number of stations, a more complicated operating technique has to be adopted in order to ensure that all the stations will be able to give their maximum output at the same time.

An example of the series system is seen in the Galloway Hydro-Electric Scheme in South Scotland where four stations operate in partial series—from natural run-off and partly from a water storage system which can be regulated to supplement the natural run-off. In operating these four stations, arrangements have to be made for their maximum outputs to be available at the same time in order to deal simultaneously with the system peak loads, and at the same time precautions have to be taken against spilling and flooding. The make up from the storage reservoir at Loch Doon is least when the natural run-off is highest, and greatest when the run-off is at a minimum in dry weather. The distance between Loch Doon and Kendoon, the first station in the series, is some nine miles, and it is necessary to release water at Loch Doon six hours before it is required at Kendoon. The stations at Carsfad and Earlstoun, which are unattended and remotely controlled, are one and a half and four miles respectively downstream from Kendoon and use the water in series from Kendoon. The water leaving the Earlstoun station joins up with the water from the Glenlee station, which is fed from its own reservoir at Clatteringshaws; and the combined waters, together with the additional run-off, supply the lowest station at Tongland.

Two diagrams illustrate different loading conditions




*Figs. 3 & 4. Examples of loading diagrams associated with the Galloway water power scheme*

on this system. Fig. 3 shows a winter condition in which a large natural run-off reduced the call on the storage at Loch Doon, while Fig. 4 shows an early summer condition, when the natural run-off is small and extensive use is made of the Loch Doon storage.

These remarks have referred briefly to some of the salient points associated with the design and operation of hydro-electric schemes for meeting the peak loads on a system. In planning these schemes the best results will only be obtained if careful thought is given not only to the civil and mechanical aspects of the design, but also to the operational technique employed.

# Responsibilities in relation to Forestry

By Roy Bridger. The world-wide problems of soil erosion are recognized. Hydro-electric engineers are urged to take precautions when planning their catchment areas to prevent long-term damage to forestry and other natural resources.

*Les grands travaux hydro-électriques risquent de susciter le conflit entre les besoins de l'agriculture et ceux de l'industrie. L'auteur invite les ingénieurs à dresser avec prudence leurs plans de captage de façon à ne pas endommager à longue échéance la richesse forestière et les autres ressources naturelles du pays. L'hydro-électricité pour sa part n'insistera pas, dit-il, pour toute destruction nouvelle du couvert forestier, si même elle peut paraître convenir à ses buts.*

*En desarrollos hidroeléctricos en gran escala existen posibilidades de que la agricultura y la industria se hallen en campos opuestos. El autor hace resaltar las precausiones que los ingenieros deberían tomar al plantear sus superficies de captación para impedir que con el tiempo puedan detrimentarse la riqueza forestal y otros recursos naturales del país. Por su parte, el autor dice, la electricidad hidráulica no exigirá el retiro de recursos forestales, aún en los casos en que esto parezca que pueda adaptarse a sus intereses.*

AT no point perhaps are the needs of agriculture and industry more likely to come in conflict than in connection with large-scale hydro-electric developments. Agriculture is concerned with primary production and must base its methods on an understanding of nature's permanent principles. Industry, as it has shown itself so far, is characterised by heedless consumption of raw materials without adequate return. It is not interested in where these materials come from nor is it concerned with natural costs. It is concerned a great deal with financial costs, and to market mass-produced goods at an attractive price the leading industrial nations had to find cheap supplies of raw materials, cheap labour to process them and cheap power to run the machines.

While they were forthcoming these elements enabled the industrial machine to function. To-day severe modifications are taking place. Many countries oversea are establishing industrial systems which increase the competition for raw materials already depleted by destruction of the forests and by the heavy soil mining. Ever increasing output is to-day the keynote, but it is all being drawn on limited reserves of soil fertility.

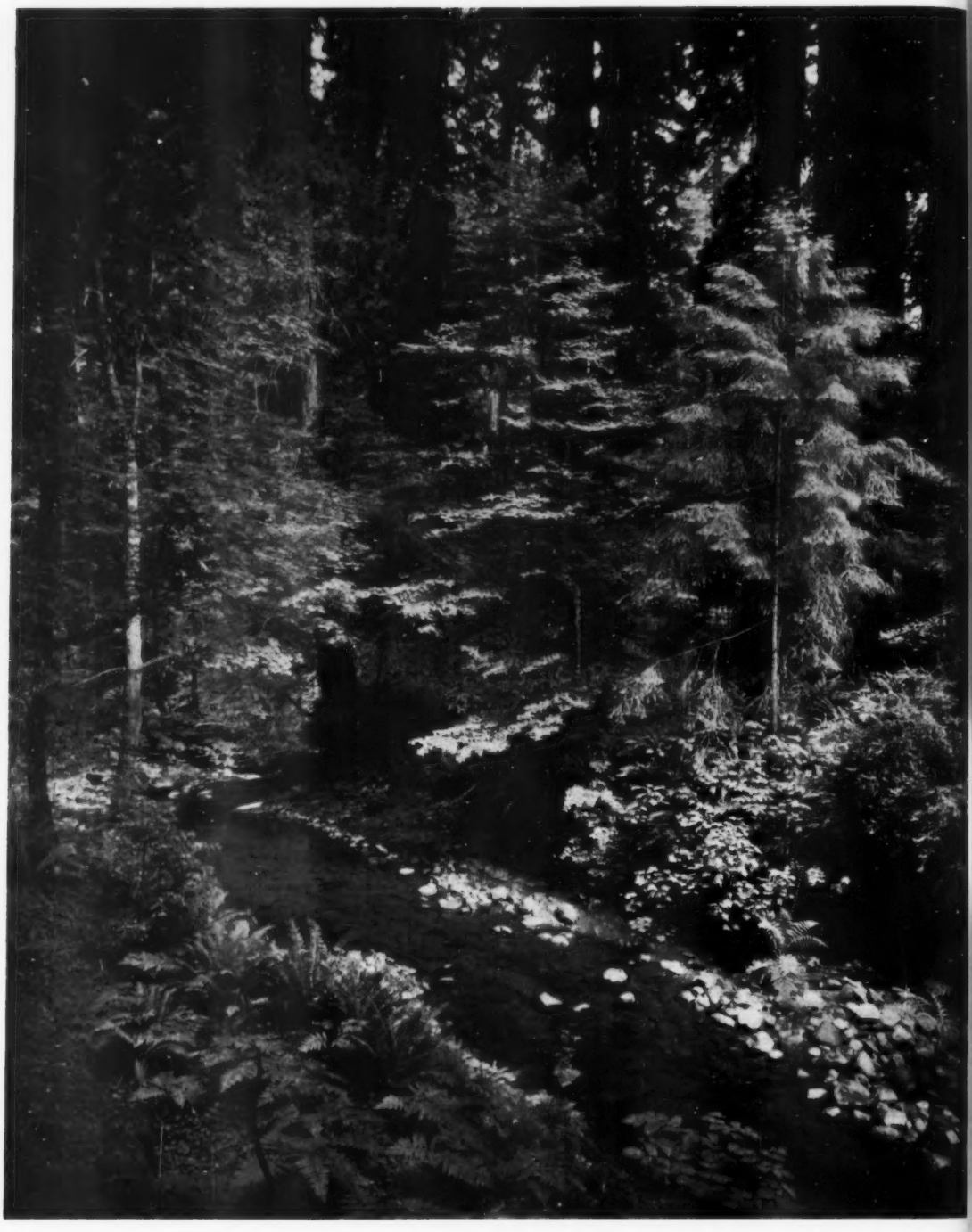
The industrial revolution has accelerated the destruction of the world's forests to a suicidal degree. Rising transport costs are proving an embarrassment. Political upheavals, major and minor wars, and a general neglect of the fundamental needs of the soil have resulted in widespread shortages and famines, and hungry multitudes, particularly in the East, are demanding their own food from areas where formerly industrial cash crops were grown. Labour is now generally too self-conscious and well organised to be cheap. The existing power supplies too are presenting problems, not only of maintenance (coal) and transport (oil) but even of possible exhaustion. At this point the entry upon the scene of a source of power, as plentiful as rain and almost as cheap, must seem to hard-pressed industrialists like the dawn of a new era.

Whether the minority view that large-scale hydro-electric undertakings would create more problems than they solved should be heeded, or whether in a falling industrial economy they would become redundant, is not here in question. What we are now concerned with are the precautions hydro-electric engineers should take when planning their catchment areas, to prevent long-term damage to the country's forestry and other resources.

**Flooding – cause or effect?**

The floods which occur on the big rivers are described as "natural," but there is reason to believe that they have occurred only since the removal of the natural forest cover which absorbs the rainfall, particularly in the upper reaches. The floor of the forest is constantly being enriched by the residues of tree and animal life, converted by aeration and the fine spray caused by the break-up of rainfall into humus. The porous soil becomes like a sponge, storing surplus moisture to be taken up by root systems and to find its way back into the atmosphere by transpiration from the leaves. In this way a steady supply of atmospheric moisture is always forthcoming to provide rain for the crops. Widespread interference with this mechanism gives rise to prolonged droughts, which science attempts to alleviate by cloud-bursting methods, but the hard facts are that these misfortunes can be overcome only by removal of the causes.

The water that remains after the forest's needs have been satisfied is released gradually, in a steady flow. With the removal of the natural cover an increasing volume of water begins to run off the land, a process which is often intensified by monoculture and other



*Photograph from the Gabriel Moulin Studios, San Francisco, Calif.*

*"The Forest is the Mother of the Rivers"*
*— Notice the clearness of the water*

*Restoration Work: Gully scalped and planted, and below—The same Gully after five growing seasons. The black locust trees average about 15 ft. in height*

soil-exhausting practices in the exposed areas. It is thought that prolonged deforestation in the upper reaches of the Chinese rivers is the cause of the present turbulent nature of the rivers, with their catastrophic floods. The Mississippi, Ohio, and other rivers in the United States of America have similar histories. With few exceptions (*e.g.*, the routine anti-erosion measures constantly being carried out in Japan) nothing is done to restore the balance by replanting; instead, attention is focussed on flood control measures such as the construction of large dams. It is significant that the most potentially dangerous flood of recent times occurred in the region of the world's largest dam. When the Columbia River flooded early in 1947 the banks of the Grand Coulee held though anxiety was felt that they would not. If they had not the city of Portland and the surrounding districts

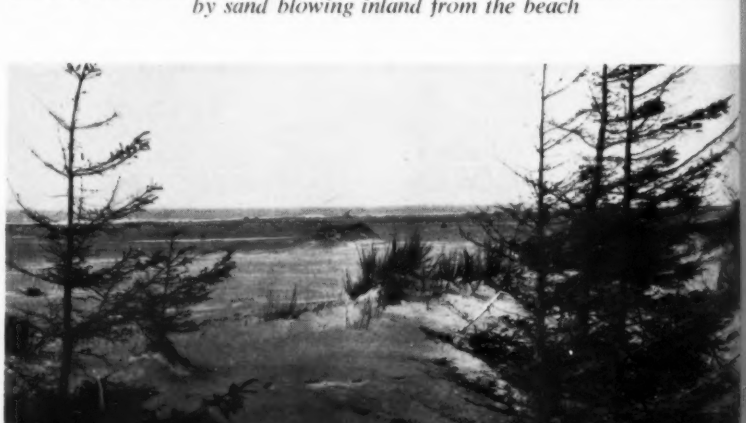
would have been inundated.

Repetitions in miniature of these disastrous floods are already occurring in Scotland, notably on the Rivers Findhorn and Nairn and on the East Coast rivers rising in the treeless Lammermuirs and Cheviots.

**Silting-up Problems**

The humic floor of the forest not only acts as a sponge for the absorption of surplus rainfall but has the equally valuable property of holding in its "cement" the mineral particles of the soil which would otherwise be washed out. This is what happens noticeably on steep rocky slopes, the weathering of which may even mean the slow build up of soil downstream. The removal of the natural protection is causing a vast and unbalanced acceleration of this process over large areas. Humus formation is stopped, erosion sets in and the gathering waters become

*Sand blown from west burying a cedar forest to the east. Below: Dune burying forest land. Note how these trees have been severely sand blasted by sand blowing inland from the beach*



*Sand-dunes burying alder, willow, and grassland*

charged with soil particles. The Yellow River bears enormous quantities of eroded soil to its mouth. The Chinese have never been able to control their rivers in their entire length nor visualise them as natural drainage systems. Now the waters of the Yangtse are to be " controlled " by the construction of the world's largest dam. Other rivers are given to changing their courses because of the unreliable beds they form, and the vast quantities of silt deposited at the estuary.

When a dam has been built the silt becomes an ever-present and increasing problem. In the still waters of the reservoir it falls slowly to the bottom; extended operations are needed for the removal of material which in the river's natural drainage system would be held at the source.

Like the hydro-electric engineer the sanitary engineer would prefer clear water. Speaking at the annual conference of the Royal Sanitary Association of Scotland, Sir Hugh MacKenzie of the North of Scotland Hydro-Electric Board admitted that the mixing of different waters was apt to have disastrous effects on the resulting product as a beverage but that modern filtration could produce first-class drinking water from very unpromising liquids. The findings of nutritional research have established the principle that food is best consumed fresh and unrefined on the spot and that modern industrial nations are paying severe health penalties for having relied too much on preserved and processed foods. It is likely that similar elusive qualities are present in water.

The world-wide problems of soil erosion, malnutrition and famine call for something more constructive than the old irresponsible banditry for selfish ends. The growth of public spirit, if not of public ownership, may ensure that in future a better balance is attained than hitherto. A repentant industry will do its best to repair the ravages of the past; for example by the use of machinery as an aid to permanent husbandry, rather than to speed up previous exploitation processes. For its own part hydro-electricity will not press for the removal of any further forest cover, even where it may appear to suit its purposes. It would be appreciated if hydro-electric undertakings were to play a part in the restoration of conditions in their catchment areas. This might take the form of subsidies and grants for land drainage and reclamation, for the improvement of grassland (itself another form of natural cover) and the establishment of woodlands. In this connection it should be remembered that real forestry means permanent mixed forestry, not as at present the monoculture of certain trees in industrial demand (*e.g.*, larch) which contribute very little to humus formation, leaving the ground acid and impoverished.

*Acknowledgment is made to Mr. Richard St. Barbe Baker, author of "Green Glory," and the Lutterworth Press, publishers of the book, from which the illustrations were taken*

# From the Journals of the technical institutions, and other material published in the Press of the World

## Tidal Power and the Severn Barrage

At a joint meeting of the Institutions of Civil and Electrical Engineers, held at the Institution of Electrical Engineers on February 5, Mr. H. Headland, M.Sc., M.I.C.E., M.I.E.E., presented his paper on "Tidal Power and the Severn Barrage."

The importance of coal conservation has renewed interest in tidal power development and the subject is introduced with a review of the principal projected schemes in various parts of the world.

The principles of single and double tide working are outlined and consideration is given to their application under the conditions prevailing in the Severn Estuary.

### Method of Working

Calculations made in 1944 confirmed that single basin ebb-tide working would give the best results for the Severn Barrage scheme. The operations concerned in ebb-tide working are:—

(a) *Filling phase.*—The turbines are shut down and the inlet gates closed. When the upstream and downstream water levels are equal the inlet gates are opened and the rising tide fills the basin. The inlet gates are closed at high water.

(b) *Period of Delay.*—The turbine and inlet gates are closed and the tide recedes until the minimum operating head is created.

(c) *Production Phase.*—The inlet gates are closed and the turbine gates are opened to (i) discharge water for power generation and (ii) control the level in the basin so that it falls more slowly than the receding tide.

Turbine operation continues until the minimum operating head is re-established by the rising tide.

The 1933 Brabazon Committee Report suggested a tidal power station, supplemented by pumped storage, which could be constructed in 15 years. In 1944 these proposals were reviewed for the Ministry of Fuel and Power with particular reference to coal conservation. The 1945 Report confirmed the 1933 committee's recommendations in respect of single basin ebb-tide working, but proposed alternative designs which could be constructed in eight years. The modifications recommended were:—

i. The installation of 32-25MW units instead of 72-12 MW machines.
ii. Omission of pumped storage and the road and railway crossing.
iii. Parallel operation with the 132kV grid transmission system.
iv. Construction of a new tidal model.

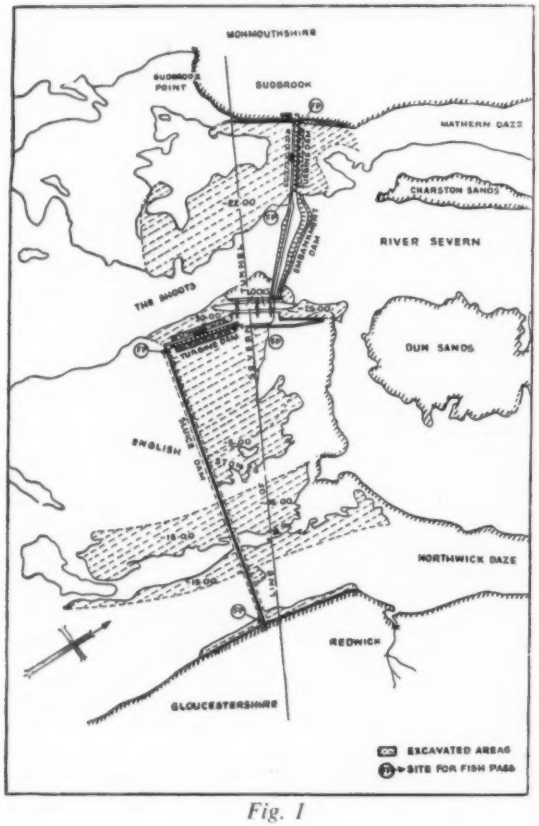



*Fig. 1*

### Features of the Severn Barrage

The general lay-out of the barrage is shown in Fig. 1. It consists of a dam 6.825 feet long across the English Stones, containing 128 sluices 31 of which are set in a deepened natural channel. Two turbine dams, each 2,250 feet long, accommodating 16-25MW units are located near the Monmouth shore and adjacent to the Shoots which are closed by an embankment dam 4,000 feet long. This channel is 60 feet deep and 1,200 feet wide and carries currents up to 12 knots; its closure constitutes the most difficult construction problem.

Two navigation locks 70 feet wide and five fish passes are provided together with rail and service road access facilities.

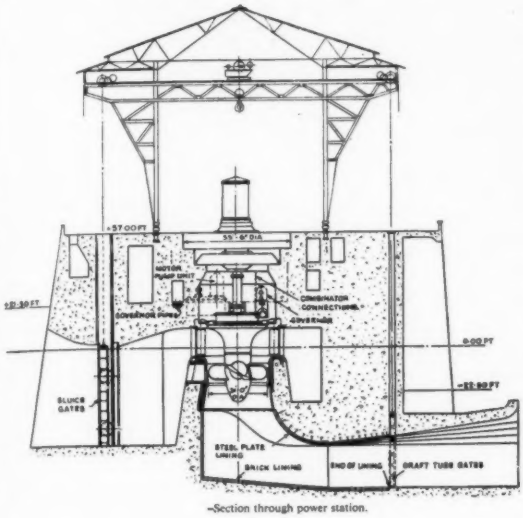
The locations of the turbine dams were determined by the following considerations:—

(a) Reduction of excavation, concentrated flow and loss of head over the English Stones, and silting along the Monmouth shore.
(b) Siting of deep foundations clear of the Severn tunnel.
(c) Location of the navigation locks.

Fig. 2 is a cross section through one of the turbine dams.

Kaplan turbines giving a nominal output of 35,000 h.p. at 40 r.p.m. were proposed. The alternators being of the vertical shaft "umbrella" type and the units

arranged in groups of four, each with a separate motor driven main and pilot exciter. The full output of 800 MW would normally be developed by 32 units,



–Section through power station.

*Fig. 2*

but the overload capacity of the turbines and the design of the alternators were such that if necessary the full output would be available from 28 machines.

**Indirect Output Regulation**

Output regulation is considered. Direct regulation does not overcome the difficulties inherent in single-basin ebb-tide working at the Severn Barrage. Indirect methods are technically acceptable and these are therefore enumerated.

Pumped storage is not recommended because the high capital cost and losses associated with it render it uneconomic as an ancillary to the tidal power station alone. Parallel operation of tidal and normal hydro-electric power stations might show satisfactory overall economy if adequate storage were available at the latter. When the tidal power predominates stability and control might introduce operating difficulties. Transmission is important and in relation to the Severn Barrage, the water power resources of North Wales are, at present, inadequate and those in North Scotland too remote for consideration.

Gas turbine plants of sufficient capacity to create the necessary proportion of firm power might be possible when adequate operating experience and larger and cheaper units become available for use with electrolytic hydrogen, blast furnace gas or pulverized coal.

If tidal power were fed into a network the following conditions would result:—

(a) The output of the other power stations could be reduced.
(b) The plant capacity required to serve the load would remain unchanged.
(c) There would be (i) fuel saving in thermal stations offset by banking losses since boiler steam pressure must be maintained, (ii) possibly some reduction in wear and tear due to reduced plant-running time, and (iii) loss of tidal energy in transmission to load centres.

The Severn Barrage would save the running component of the fuel consumption, and possibly a proportion of the costs of oil, water and stores, repairs, maintenance and renewals, but not salaries and wages, since personnel required is unchanged.

Although transmission to load centres introduces operating problems it utilizes the tidal energy to the best advantage. A system was described for transmitting power from the barrage to heavy load centres showing that threequarters of the energy would be transmited at 220 kV to south-east and central England where it would be stepped down for connection to the grid.

**Economic Considerations**

In 1944 the capital cost of the barrage and associated works was estimated to be £47 million, the present cost of this scheme being in the order of £60 million. The 1944 total cost was allocated as follows:—

| | |
|---|---|
| Civil Engineering Works ... ... ... | 45.30% |
| Generating Plant ... ... ... ... | 31.30% |
| Transmission lines and substations ... | 13.60% |
| Interest during construction ... ... ... | 9.80% |

The annual cost of operating the project would amount to 5.14% of the estimated capital expenditure.

The annual charges determine the cost of energy delivered to the load centres and these, together with the coal saved in thermal stations by combined operation, provide the economic basis for judging the value of tidal energy.

The conditions for the development of tidal power are enumerated and the author concludes that the future possibilities for tidal power development are not unfavourable, and further investigation of economic factors, constructional methods, and plant design are justified.

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## INDIA AND PAKISTAN

Co-ordination of schemes for doubling the present power production in India was an outstanding aim of a conference of power engineers from all over India held recently in New Delhi. The Indian Minister for Mines and Power (Mr. N. V. Gadgil) declared that engineers must break down the cost of the schemes into yearly figures, which in turn must be commensurate with the country's spending capacity. On the prime importance of co-ordinated planning when implementing power projects the Minister said the function of the electricity boards to be established in each of the provinces was to arrange for the expansion of the existing power systems and the construction of new stations, in order to make power available economically over wide areas.

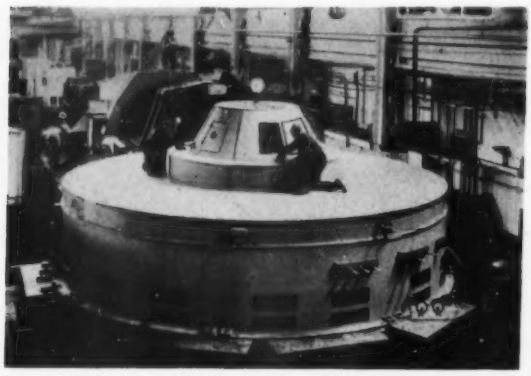
New hydro-electric projects in hand in the Provinces will provide generating capacity of about 3 million kW, additional to the present installed capacity of about 2.2 million kW.

Pakistan, lacking indigenous fuels, attaches high priority to hydro-electric works, and three major schemes occupy the Government's attention. One will almost double the capacity of the Malakand station, while a second will use the waters of the Upper Swat canal after discharge from the Malakand works for a duplicate plant at Dargai. The biggest scheme, at Warsak, will ensure supplies of between 75,000 and 100,000 kW to the West Punjab and irrigation to large areas around Peshawar.

# Contractors' Notes

**Allis-Chalmers Manufacturing Company.**—A contract has been placed for switchgear to control a 2,250 kVA hydraulic-driven generator for Cia Industrial de Guadalajara, Mexico. The switchgear will be installed at a steam plant for the remote control of the associated hydro station which is situated about a mile away. Allis-Chalmers Manufacturing Co., Milwaukee, and Canadian Allis-Chalmers, Ltd., Toronto, announce that they have entered into an agreement which establishes Canadian Allis-Chalmers as a distributor for products and repair parts of the Milwaukee concern's general machinery division in Canada and Newfoundland. The new relationship permits Canadian Allis-Chalmers to make direct sales to customers.

**British Thomson-Houston Company.** — The State Hydro-Electric Department of New Zealand has ordered seven 16,667 kVA, single-phase, 50-cycle naturally cooled transformers for forming two 50 MVA, 3-phase, 220/110/11 kV banks, connected star/auto with a delta tertiary winding supplying 30 MVA synchronous condensers. Export orders which have been completed and despatched during 1948 include

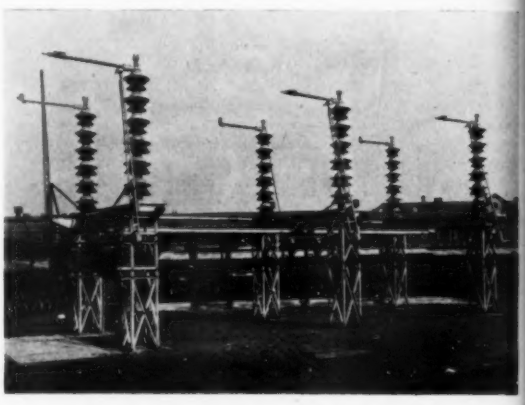


*First of three B.T.H. 18,900 kVA units for Clunie*

a number of 66 kV and 132 kV transformers, ranging from 2,000 kVA to 15,000 kVA for the Raul Hydro-Electric Project in West Punjab; and two 37.5 MVA, 11/6.6 kV units for the State Electricity Commission of Victoria, Australia.

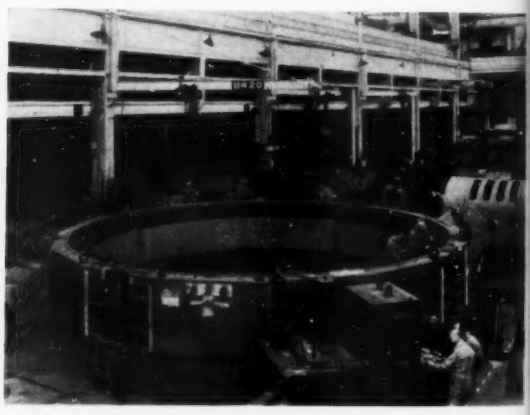
**Harland Engineering Company, Scotland.** — Among the orders placed by the North of Scotland Hydro-Electric Board is one for the Storr Lochs power station. Situated remotely in the Isle of Skye, it will run unattended in parallel with the recently completed 1,000 kW Nostie Bridge power station in the Kyle of Lochalsh. The two horizontal-shaft Francis water turbines by Gilbert Gilkes and Gordon, will each be coupled to a 1,000 kVA, 3,300 volts, 3 phase, 50 cycles Harland alternator. They will be provided with a comprehensive protective scheme to shut down either or both sets in the event of mechanical or electrical fault and also arranged for manual starting and stopping. While contracts are at present restricted to the two sets now in course of manufacture, it is intended that the eventual total installed capacity of the station will be 3,000 kVA.

**Metropolitan-Vickers Electrical Company.**—The first of three 18 MVA generators for Tainionkoski (Finland) is being assembled on site, and the second will



*220 kV Type AAR Airbreak Switch*

be shipped shortly; assembly of these two machines on site was decided upon in order to have them in operation at the earliest possible moment. The Tainionkoski generators will run at 75 r.p.m., this low speed requiring unusually large diameters and heavy



*30 ft. Stator of an 18,000 kVA Vertical Waterwheel alternator for the Tainionkoski Scheme*

rotor rims. One of two smaller vertical shaft machines in hand for Pitlochry (North of Scotland Hydro-Electric Board) is now being prepared for works tests.

Among new orders are several for horizontal shaft generators to be driven by Pelton wheels. Two of 35 MVA for the Aura power station, a key-point of the new hydro-electric developments in Norway, will be among the largest in output so far made in this country, and two of 16,000 kVA for Pykara (India) will be driven at 600 r.p.m. by single wheels with outboard bearings (as on the 12,500 kVA machines previously supplied to this station). Liquid loading resistances are under construction for a 50 MW waterwheel generator for Portugal.

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